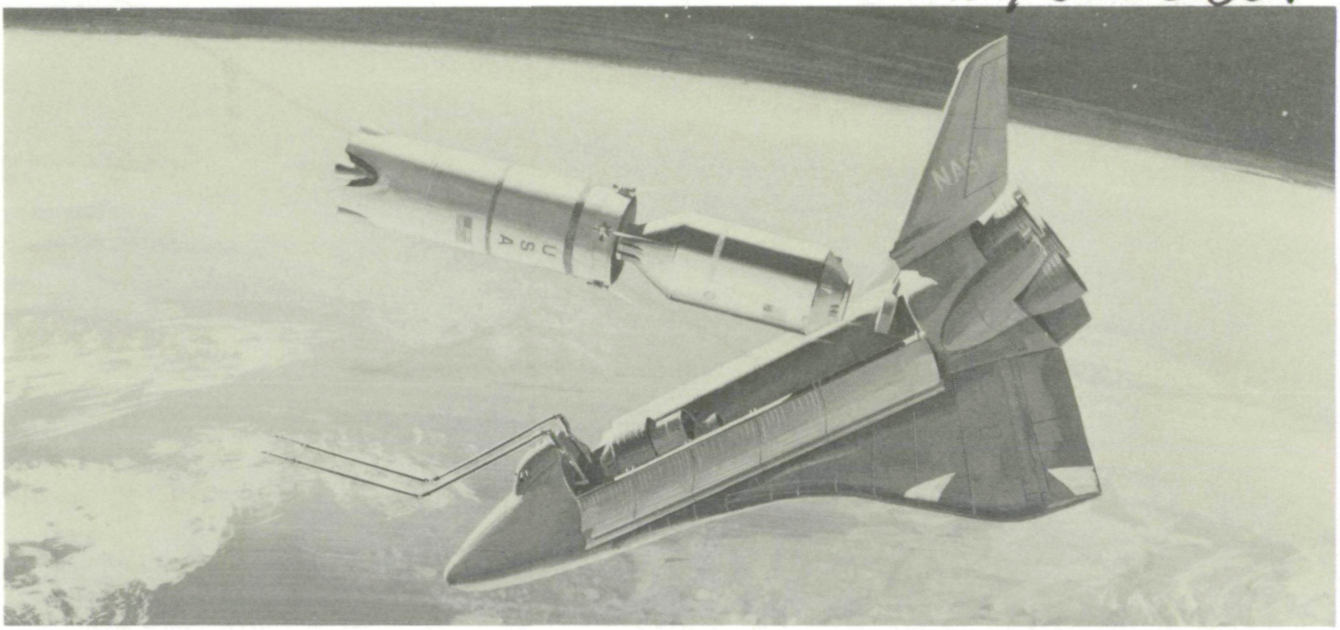
CONTRACT NAS8-27692
DR NO: MA-04

SD 72-SA-0053-2
JUNE 23, 1972

**IN-SPACE PROPELLANT
LOGISTICS AND SAFETY**

N72-30801



IN-SPACE PROPELLANT LOGISTICS

Volume II
TECHNICAL REPORT

Space Division
North American Rockwell

12214 Lakewood Boulevard, Downey, California 90241

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Volume II
TECHNICAL REPORT

R.E. Sexton

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North American Rockwell

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FOREWORD

This In-Space Propellant Logistics and Safety Study was performed by the Space Division of North American Rockwell Corporation for the National Aeronautics and Space Administration, Marshall Space Flight Center, under Contract NAS8-27692. The study was a twelve-month effort initiated on June 25, 1971, and completed on June 23, 1972.

The study was conducted as two separate, but related projects. One project addressed the systems and operational problems associated with the transport, transfer, and storage of cryogenic propellants in low earth orbits, while the other project addressed the safety problems connected with in-space propellant logistics operations. Correlation between the two projects was maintained by including safety considerations resulting from the System Safety Analysis in the trade studies and evaluations of alternate operating concepts in the Systems/Operations Analysis.

Walter E. Whitacre of Marshall Space Flight Center, Advanced Systems Analysis Office, was the Contracting Officer's Representative and provided technical direction to the overall contract and to the Systems/Operations Analysis project; Walter Stafford of the same office provided technical direction to the System Safety Analysis project. The contractor effort was under the direction of Robert E. Sexton, Program Manager; the Systems/Operations Analysis effort was led by Robert L. Moore and the System Safety Analysis effort was led by William E. Plaisted.

This document is Volume II of the following five volumes which contain the results of the Systems/Operations Analysis:

Volume I	Executive Summary	(SD72-SA-0053-1)
Volume II	Technical Report	(SD72-SA-0053-2)
Volume III	Trade Studies	(SD72-SA-0053-3)
Volume IV	Project Planning Data	(SD72-SA-0053-4)
Volume V	Cost Estimates	(SD72-SA-0053-5)

The results of the System Safety Analysis portion of the study are contained in the following three volumes:

Volume I	Executive Summary	(SD72-SA-0054-1)
Volume II	System Safety Guidelines and Requirements	(SD72-SA-0054-2)
Volume III	System Safety Analysis	(SD72-SA-0054-3)

This volume contains the analyses and major results of the study leading to the definition of a representative in-space propellant logistics system and its operation. Included in this portion of the report are the results of an analysis to determine in-space propellant requirements in support of the NASA space program plan, definitions of propellant logistics system concepts to meet these requirements, and a cost analysis of these concepts leading to the selection of a cost effective concept. The latter is further analyzed for the impact of in-space propellant logistics operations on major hardware elements. The results of a maintenance and manned support requirements analysis are also included.

ACKNOWLEDGEMENTS

The contributors to Volume II of this report include the following:

J. Hermann	Propellant Requirements and Space Traffic Models
G. A. Olson	Space Traffic Models and Payload Propulsive Stage Definitions
A. R. Jusak	Payload Propulsive Stage Definition
D. A. Thome	System Concepts Integration and Design
D. W. Triplett	Propellant Transfer and Subsystem Analysis
W. R. Beswick K. L. Davis C. M. McCrary	Propellant Transfer Analysis
P. Sherman	Subsystem Trades
R. J. Milliken	Overall Systems Analysis and Interfaces
T. J. Dolan	Operations Analysis
R. A. Pople	Interfaces Analysis
W. R. Gardner	Traffic Model Analysis
T. S. Logsdon T. F. Rudiger S. T. Cerri	Flight Mechanics
D. J. Watanabe	Overall Systems Analysis Support

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1.0 INTRODUCTION

1.1 BACKGROUND

The National Aeronautics and Space Administration space program plan (1975-1995) encompasses a multitude of elements including space-based and ground-based vehicles for transporting payloads from low-earth orbit to geosynchronous, lunar and planetary orbits. The space-based vehicles require large quantities of propellants (primarily liquid oxygen and liquid hydrogen) and must be refueled periodically while in earth orbit. This defines the need for propellant logistics which encompasses earth-to-earth orbit transport, earth orbital storage and in-space transfer of these propellants.

A vital step in the successful development and execution of the space program plan is the early definition of the propellant logistics elements and the date when initial operational availability is required. In addition, funding requirements, schedules, and the impact on other program elements with respect to design and operational considerations must be defined for the timely and effective planning to meet the overall goals and objectives of the space program.

To provide this vital information, an overall systems/operations analysis of the NASA space program plan has been conducted and the results are reported herein. Issues of great significance have been addressed and resolved, such as:

a. the time-phased quantities of in-space propellant requirements

b. the cost effectiveness of orbital storage both with and without an orbital storage depot

c. the impact of propellant payloads on the space shuttle payload requirements

d. evaluation of in-space propellant transfer techniques

e. propellant logistic implications of payload orbit inclination and altitude

f. identification of credible in-space propellant logistics concepts and evaluation of their cost effectiveness.

This technical volume contains the development of a parametric space program plan and corresponding propellant requirements, a broad spectrum of in-space propellant logistic concepts, mission planning requirements, hardware configurations, interface requirements and program costs. A more detailed analysis of a representative propellant logistics concept provides the basis for the program development and implementation requirements which are contained in Volumes IV and V.

Of more value than the specific conclusions regarding a baseline propellant logistic system is the strong parametric nature of the basic data generated

in this study. These data will find many applications in evaluating future modifications to the NASA space program plans.

1.2 STUDY APPROACH

The overall systems/operations analysis involved the establishment of propellant requirements based on a review and analysis of the NASA space program plan, the formulation of propellant logistic operational concepts, a cost analysis and concept selection, and the design and operations analysis of a representative concept. The analysis included the establishment of relative costs for propellant logistics during the 1979-1990 time period for five space program models, the selection of a representative logistic operational concept for supplying propellants to space-based vehicles, and the establishment of an interface definition and an implementation plan for the selected concept.

Among the ground rules established during the study were: (1) the space shuttle as the basic delivery system for delivering payloads from earth to low earth orbit, (2) the use of ground-based and space-based vehicles for payload placement from near earth orbit to higher orbits and beyond, (3) liquid hydrogen and liquid oxygen as the only propellants, and (4) the NASA space program plan as the basis of the study.

The foundation of the propellant logistic system analyses is the 12-year (1979-1990) NASA space program model defined for this study. This model defines the payload placement missions and the number of times each mission is executed (number of placements) per year for the 12-year period. Using this model as the baseline, four additional program models were developed during the study to provide reasonable coverage of NASA planning options. To develop these additional models, a review of NASA space program projections and classification of major alternatives were completed to identify the missions, the vehicles and operational modes related to these missions for the delivery and placement of their payloads.

For each space program model, consisting of a variety of missions, a space traffic model was established. This traffic model indicates the vehicle by which each mission payload is placed in space and its schedule (by years) for placement. Payloads whose placements are within the capability of the baseline shuttle were identified. For payload placements beyond the shuttle capability, payload propulsive stages (PPS) are utilized in conjunction with the shuttle orbiter. The shuttle orbiter was assumed to deliver the payload to near earth orbit, and then a payload propulsive stage would boost the payload from near earth orbit to its final destination. Both ground-based and space-based payload propulsive stages were considered in this study.

The designation of a specific payload propulsive stage for each of these payloads was done on the basis of the early availability (1979-1984 period) of ground-based, expendable PPS's and their capabilities and later availability (1985-1990 period) for the space-based, reusable PPS's. The three classes of vehicles designated (ground-based expendable, ground-based reusable, and space-based reusable) represent increasing levels of desirability since each class of vehicle provides a greater degree of space program flexibility and requires

greater funding. (Operational availability of a ground-based and/or a space-based tug is assumed to be a function of space program funding.) The three classes of placement vehicles have been applied to each 12-year program activity level in one or more combinations to reflect a credible spectrum of availability options.

Since one of the objectives of the study was to determine the most cost effective method of implementing each program level, it was necessary that the cost be determined for the entire 12-year period for each combination of placement vehicles (i.e., each implementation option) in a given program level. Necessarily, then, the propellants for ground-based vehicles are included in the definition of "in-space" propellants.

The propellants required by the payload propulsive stages to perform the payload placements establish the in-space propellant requirements. Thus, propellants required for each payload placement, the annual and the total quantities required for the 12-year period were established for each space program model. These requirements include estimated propellant losses that will occur during delivery from earth to low earth orbit and propellant transfer, and boil-off losses from the PPS while in orbit.

Based on these propellant requirements, various propellant logistic operational concepts were formulated which consist basically of a means for transporting propellant from earth to low earth orbit and the method for on-orbit transfer and storage. For ground-based PPS's, the logistic operational concept is simple and straightforward since the propellants are loaded directly on the PPS while on the ground and then transported to orbit. The basic concept utilizes the shuttle orbiter to transport the ground-based PPS, its propellant and mission payload to low earth orbit. For those cases in which the propellant requirements for payload placement exceed the capacity of a single PPS and/or the payload capacity of a single shuttle, two or more shuttles would be utilized. Assembly of two PPS's and/or PPS and scientific payload would have to be performed in orbit.

For space-based payload propulsive stages, several operational concepts were considered. These included direct delivery of propellants to the PPS and delivery of propellants to an on-orbit storage facility, from which propellant would be transferred to the PPS. The propellant quantities and delivery schedule for each payload placement, delivery modes and the design and operational concepts of the PPS's are all considered in defining the various concepts.

The direct delivery concept is ideally suited for the case when the propellant requirements, quantity and schedule, are matched by the capability of the delivery vehicle. For logistics concepts with on-orbit storage, a large depot, a small depot or mini-depot, and the use of a second PPS for storage as well as for payload placement were among the methods considered.

For payload delivery by the shuttle orbiter, the cargo capacity, orbit altitude and inclination capability, and the make-up of the cargo (whether combined propellant and mission payload, or propellant alone) were considered in establishing the delivery mode to minimize the number of shuttle flights.

An alternate propellant delivery mode which consisted of the shuttle booster and an expendable second stage (ESS) was also considered. This mode provides a large quantity of propellant per delivery; and it was compared with the shuttle delivery mode to establish the preferred delivery mode.

For this study, all the space-based PPS's considered were designed for fluid transfer rather than modular transfer, and so the appropriate emphasis was placed on the investigation of in-space fluid transfer techniques.

From the large number of possible operational concepts, the most viable concepts were selected for further analysis. For these viable concepts, the number of shuttle flights necessary for propellant delivery as well as for payload placements were determined for each of the space program models. This established the logistic traffic models which provided the basis for a cost comparison and subsequent selection of a representative logistic operational concept.

Cost effectiveness has been a paramount consideration throughout the study in order to achieve a minimum cost program. To establish the most cost effective concept or concepts, cost analyses were conducted to provide cost data for comparison. All significant factors were included in establishing the cost estimates. Development, production and operation costs and any modification costs were included for all hardware dedicated to propellant logistic use. Only operations costs and production costs prorated to logistic missions were included for vehicles developed under separate programs but which are an integral part of the logistics concepts. The operational costs include the cost of the propellant used for delivery and also the cost of propellant losses incurred during delivery and subsequent transfer, and the boil-off losses that occur during the tanking and storage period between missions.

Cost analyses included examining operational modes to determine the mode or modes that result in least cost. Also, major cost drivers were identified, which help to give direction to reducing cost. To conduct the cost analysis, the cost data, a rough order of magnitude costs, were derived from existing studies and programs.

The results of the cost analyses provided the basis for selecting a representative logistic operational concept. For the selected concept, a sensitivity analysis was conducted to determine the cost sensitivity to the variations in the potential growth (weight and size) of the scientific payloads, the capability of the delivery vehicle, and the design of the user vehicle.

A description of the selected concept which includes the definition of the propellant logistic modules (used for transport in the shuttle cargo bay) and their interfaces and the description of the logistic operation have been completed. The level of detail is only to the extent necessary for a thorough understanding of the concept and for use in cost estimating.

Maintenance requirements and the role of man are included in the discussion.

Recognizing that the selected logistic system concept is based on current projections for propellant requirements and current definition of space program

elements, modifications to the selected concept as well as the possibility of a different or new concept need to be considered as better definition and changes in the space program occur. With this in mind, the broad conceptual and operational influences on the space program and its elements associated with the implementation of propellant logistic systems are presented. Significant interrelationships among the shuttle orbiter, the space-based user vehicles and the logistic module elements established by the in-space propellant logistics analyses are reviewed.

2.0 SUMMARY AND CONCLUSIONS

To provide a parametric data base, a space program plan consisting of five different levels of activity was derived from the NASA Payload List (Fleming Model). Propellant requirements were determined for payload propulsive stages which perform scientific payload placements in the five program levels. Propellant logistic system concepts for implementation of the placement missions were established, and costs were calculated for propellant logistics operations with these concepts in each of the five program levels. A representative concept was selected as a baseline for an interface definition. This concept was used as the basis for the development of an implementation plan to provide an in-space propellant logistics capability by 1985.

Significant study results and conclusions are as follows:

a. In-space propellant requirements range from a minimum of 100,000 pounds per year in the lowest program activity level to a maximum of 4,800,000 pounds per year in the highest level.

b. Of the two earth-to-earth orbit transportation systems investigated (shuttle orbiter and shuttle booster plus expendable second stage), the shuttle orbiter provides for lower transportation costs on a dollars-per-pound basis.

c. Propellant has been determined to represent an average of 70 percent of the total cargo to be carried to space by the shuttle.

d. Implementation of all payload placement missions over the 1979-1990 time period requires a minimum of 184 shuttle flights in the least ambitious of the five program levels. For implementation of the placement missions in the most ambitious program, the required number of shuttle flights is 789 over the 12-year period, employing a cost effective logistics concept. Additional shuttle flights are required for missions that do not involve a payload propulsive stage (some physics and astronomy missions and all sortie and space station missions).

e. In-space propellant transfer is feasible within the present state of the art. The technology should be improved for high performance low thrust propulsion systems (required for propellant settling) and for zero gravity propellant quantity sensing.

f. Some form of in-space propellant storage is required for a cost effective space program; however, an orbiting propellant depot is not required.

g. A self storage concept for a space-based tug operation and for CIS/RNS operation satisfies the requirement for in-space propellant storage.

h. A propellant logistics module for carrying propellant to space in the shuttle cargo bay is required for an in-space propellant logistics capability.

i. Relative logistic system operational costs are insensitive to variation in program level, i.e., the most cost effective concept is the same regardless of space program activity level.

j. Space program costs are very sensitive to shuttle orbiter cargo capacity. A reduction of either weight capacity or cargo bay length will increase costs appreciably.

k. The space-based tug defined for this study has a lower mass fraction than the ground-based tug (OOS). Since a higher mass fraction tug tends to result in lower program costs, consideration should be given to providing the ground-based tug (high mass fraction) with space-basing capability.

l. Program costs are less sensitive to an increase in payload weight or length than to changes in shuttle orbiter capacity.

m. The role of man required for in-space propellant transfer is within the normal operational duties associated with space shuttle operation.

n. Phase D effort for the propellant logistics module should start no later than January 1979 for an in-space propellant logistics capability by 1985.

The parametric nature of the data presentation (five space program activity levels, two 6-year time periods, and three vehicle implementation options) lends itself to the application of the results in future space program plans. Thus, long-term utilization of the data is anticipated.

The in-space propellant logistics operational concept selected to serve as a baseline for an interface analysis and for the development of program planning data is a representative concept. It should not be considered an absolute selection. Non-recurring costs for implementation of this concept are estimated at $158 millions, while recurring costs with the program level representing the NASA Payload List are estimated at $202 millions. Development of these costs is detailed in Volume V of this report.

3.0 IN-SPACE PROPELLANT REQUIREMENTS

For the purpose of the ISPLS study, in-space propellant logistics systems have been defined as elements which provide for the transport, storage, and in-space transfer of propellants consumed by propulsive vehicles employed for scientific payload placements at altitudes beyond the near-earth capability of the shuttle orbiter. The first step necessary for the derivation of such logistics systems is the definition of the total propellant requirements which must be satisfied. This section documents the development of these time-phased propellant requirements.

The starting point for the propellant requirements development was the NASA Payload List (Fleming Model, Table 3.1-1), which is essentially a NASA Space Program Plan for the placement, retrieval, and planetary injection of payloads during the 1979-1990 time period. The NASA Payload List was used as the basis for the development of five (5) Space Traffic Models representing variations in space program activity level, and they are summarized in the Parametric Space Program of Table 3.2.1-2. The five program activity levels reflect variations in the level of available funding for future NASA programs, and they were established by deletions from, and additions to, the basic Fleming Model. The five space program activity levels represent a unique, parametric approach to the problem of in-space propellant logistics; and since the technique employed in the analysis of the programs permits it to be used for specific portions of any existing or future space program plans, it is believed to be of lasting value. The payload placement missions in the Parametric Space Program have been divided into those which require the use of a propulsive stage and those which fall within the performance range of the shuttle orbiter. The latter have been identified in the space program summary, and their relationship to the total number of placements in each program level is illustrated by the unshaded regions in Figure 3.2.1-1. They make no contribution to in-space propellant requirements in the context of this study.

Establishment of the quantity of propellants consumed by payload propulsive stages in performing placement missions required the definition of appropriate vehicles. These have been summarized in Figure 3.2.2-1, and they include both reusable vehicles (which are fundamentally space-based) and expendable vehicles (which are fundamentally ground-based). Inclusion of ground-based vehicles is the result of the nature of the space traffic models, wherein it was assumed that reusable vehicles would be available only in the later years of the programs and/or the higher activity levels due to funding limitations in the early years. The various program level and propulsive stage combinations considered are summarized in the Program Level Composition Guide of Table 3.2.3-1 and reflect all credible options for the twelve year period for each program activity level.

The physical and performance characteristics of the payload propulsive stages and the scientific payload weights and delta-V requirements were used to calculate individual mission propellant requirements for each applicable combination of placement mission and propulsive stage. These combinations yielded the Space Traffic Models of Figures 3.2.4-1 through 3.2.4-10, which consist of the listing of each payload placement mission in each program level by year, plus the propulsive stage(s) applicable in the two halves of the 12-year time period considered in this study. The summarization of individual mission propellant requirements by year and program level yielded user propellant

requirements as a function of time, with program level as a parameter. These propellant requirements, shown in Figures 3.3.2-1 through 3.3.2-4, were subsequently used to establish propellant logistics traffic models, as documented in Section 5.0. In addition to this use, the plots of total propellant requirements illustrate that, for the vehicles defined for this study, non-reusable propulsive stage propellant requirements are significantly lower than for reusable vehicles. The effect that the introduction of the large interorbital shuttles (CIS/RNS) and their associated missions have on total propellant requirements is also shown.

One significant conclusion resulting from an examination of the propellant requirements is that propellants represent a major fraction of the total payload weight carried to orbit in the shuttle orbiter cargo bay (Figure 3.3.4-1). The data also indicate that a majority of the placements that require a propulsive stage are at orbit inclinations between 0 and 30 degrees (Figure 3.3.3-1), and they represent a major fraction of total propellant requirements.

3.1 NASA SPACE PROGRAM PLANS

The starting point for the propellant requirements development for this study was the NASA Payload List dated March 15, 1971, and issued by Mr. W. A. Fleming of NASA Central Planning. This list, or Fleming Model, is essentially a NASA Space Program Plan for the placement, retrieval, and planetary injection of payloads during the 1979-1990 time period; and it is shown in Table 3.1-1 updated as of October 1971 in accordance with NASA documentation. The role which the Fleming Model played in the propellant requirements data development is illustrated in Figure 3.1-1, which indicates that it was the baseline for the development of a parametric space program plan. This development took into account NASA space program projections, which are the subject of the material which follows.

The review of NASA space program projections was the first step in the process of identifying NASA space program requirements for use in the ISPLS study. In this review the NASA space program is used more broadly to include applications mission programs (communications, navigation and traffic control, meteorology, and earth resources) by COMSAT and civil user agencies as well. DOD-projected missions are not included.

The objective of the review of the space program projections was to relate planning data in support of the next study step which is the identification of alternate space mission programs upon which to base propellant requirements definitions.

The direction of the contemplated NASA space program is benefits-oriented. While recognizing that benefits are difficult to quantify, the President's Space Science Advisory Committee in Reference 3.1-1 suggested the following benefits areas:

a. Economic
b. National Security
c. Science

Table 3.1-1 NASA Payload Placement Model, 15 March 1971
(Updated October 1971)

MISSION CATEGORY	NO.	MISSION TITLE	ORBIT INCL (°)	ORBIT ALT (nmi)	PAYLOAD DIA X L (FT)	MISSION PAYLOAD LB	ΔV ABOVE 100 X 100 FT/SEC ①	79	80	81	82	83	84	85	86	87	88	89	90	12-YEAR TOTAL
PHYSICS & ASTRONOMY	1.	ASTRONOMY EXPLORER	28.5	270	1.7 x 2.5	720	592	2		1	2	2	1		2	1	2	2		15
	2.	RADIO EXPLORER	28.5	19300	4.5 x 3.3	720	13,000		2	1			1	2		1			2	9
	3A.	MAGNETOSPHERE EXPLORER	0	1800 x 180	4 x 8	1,200	11,783	1				1				1				3
	3B.	MAGNETOSPHERE EXPLORER	28.5	1800 x 180	4 x 8	1,200	2,510		1				1				1			3
	3C.	MAGNETOSPHERE EXPLORER	55	1800 x 180	4 x 8	1,200	2,510			1				1				1		3
	3D.	MAGNETOSPHERE EXPLORER	90	1800 x 180	4 x 8	1,200	2,510				1				1				1	3
	4A.	MAGNETOSPHERE EXPLORER	0	20000 x 1000	5 x 8	1,000	11,158	1				1				1				3
	4B.	MAGNETOSPHERE EXPLORER	28.5	20000 x 1000	5 x 8	1,000	10,720		1				1				1			3
	4C.	MAGNETOSPHERE EXPLORER	55	20000 x 1000	5 x 8	1,000	10,720			1				1				1		3
	4D.	MAGNETOSPHERE EXPLORER	90	20000 x 1000	5 x 8	1,000	10,720				1				1				1	3
	5A.	MAGNETOSPHERE EXPLORER	0	1 AU	4 x 6	600	13,099	1				1				1				3
	5B.	MAGNETOSPHERE EXPLORER	28.5	1 AU	4 x 6	600	11,000		1				1				1			3
	5C.	MAGNETOSPHERE EXPLORER	55	1 AU	4 x 6	600	11,000			1				1				1		3
	5D.	MAGNETOSPHERE EXPLORER	90	1 AU	4 x 6	600	11,000				1				1				1	3
	6.	ORBITING SOLAR OBSERVATORY	30	350	7 x 10	1,900	856		1											1
	7A.	GRAVITY/RELATIVITY EXP	85	300	5 x 7	1,500	692						1							1
	7B.	GRAVITY/RELATIVITY EXP	95	300	5 x 7	1,500	692												1	1
	8.	GRAVITY/RELATIVITY EXP	28.5	1 AU	4 x 5	500	11,000			1						1				2
	9.	RADIO INTERFEROMETER	28.5	38646	12 x 15	6,000	13,660			1										1
	10.	SOLAR ORBIT PAIR	30	19300	10 x 12	1,900	12,917						1					1		2
	11.	SOLAR ORBIT PAIR	28.5	1 AU	10 x 12	1,900	11,000						1					1		2
	12.	OPTICAL INTERFEROMETER	30	19300	7 x 10	3,500	12,917										2			2
	13A.	HEAO	30	230	10 x 34	19,700	468	1				1		1						3
	13B.	HIGH ENERGY STELLAR ASTR.	30	230	14 x 46	21,000	468				1					1		1		3
	14.	HESA REVISITS	30	230	14 x 13	3,500	468		2	2	2	2	2	2	2	2	2	2	2	22
	15A.	LST (STAR)	28.5	350	13 x 45	21,300	856			1				1						2
	15B.	LST (RAM)	28.5	350	14 x 60	30,000	856							1						1
	16.	LST (REVISITS)	28.5	350	14 x 13	3,500	856				2	2	2	1	2	2	2	2	2	17
	17.	LARGE SOLAR OBSERVATORY	30	350	14 x 54	27,000	856					1					2			3
	18.	(LSO REVISITS)	30	350	14 x 13	3,500	856						2	2	2	2	1	2	2	13
	19.	LARGE RADIO OBSERVATORY	30	350	14 x 30	19,300	856							1						1
	20.	(LRO REVISITS)	30	350	14 x 13	3,500	856								2	2	2	2	2	10
EARTH OBSERVATION	21.	POLAR EARTH OBS. SAT.	99.15	500	6 x 12	2,500	1,330	1	1	1	1	1	1	1	1	1	1	1	1	12
	22.	SYNCH. EARTH OBS. SAT.	0	19300	4 x 6	1,000	14,100		1		1		1		1		1		1	6
	23.	EARTH PHYSICS SAT.	90	400	3.5 x 6.5	600	1,020		1	1	1	1		1		1		1		7
	24.	SYNCH. METEOROLOGICAL SAT.	0	19300	5 x 8	1,000	14,100				1	1								2
	25.	TIROS	100.7	700	5 x 10	1,000	1,940			1				1					1	3
	26.	POLAR EARTH RESOURCES SAT.	99.15	500	6 x 12	2,500	1,330								2	4				6
	27.	SYNCH. EARTH RESOURCES SAT.	0	19300	4 x 6	1,000	14,100			1	2	1				1	2			7
COMMUNI-CATION/ NAVIGATION	28.	APPLICATIONS TECH. SAT.	0	19300	15 x 20	7,950	14,100	1		1		1	1		1		1	1		7
	29.	SMALL APPLICATIONS SAT.	0	19300	6.5 x 12	600	14,100	1	1	1	1	1	1	1	1	1	1	1	1	12
	30.	SMALL APPLICATIONS SAT.	90	3000 x 300	6.5 x 12	600	3,800	1	1	1	1	1	1	1	1	1	1	1	1	12
	31.	COOPERATIVE APPLICATIONS	0	19300	6.5 x 12	820	14,100	1					1							2
	32.	COOPERATIVE APPLICATIONS	90	3000 x 300	6.5 x 12	820	3,800				1							1		2
	33.	MEDICAL NETWORK SAT.	0	19300	12 x 15	2,000	14,100	2												2
	34.	EDUCATION BROADCAST SAT.	0	19300	10 x 19	2,145	14,100		2											2
	35.	FOLLOW-ON SYSTEM DEMO.	0	19300	12 x 15	2,000	14,100			2	2	2	2	2	2	2	2	2	2	20
	36.	TRACKING & DATA RELAY	0	19300	12 x 15	2,300	14,100	1	2	1		2	1			2	1			10

① THEORETICAL MINIMUM, ONE-WAY, POINT-TO-POINT ΔV

Table 3.1-1 NASA Payload Placement Model, 15 March 1971 (Updated October 1971) (Part 2)

MISSION CATEGORY	NO.	MISSION TITLE	ORBIT INCL (°)	ORBIT ALT (nml)	PAYLOAD DIA X L (FT)	MISSION PAYLOAD LB	ΔV ABOVE 100 X 100 FT/SEC ①	79	80	81	82	83	84	85	86	87	88	89	90	12-YEAR TOTAL
								SCHEDULE OF PLACEMENTS												
SORTIES	38.	GEN. SCIENCE RES. MODULE	55	200	14 x 54	27,500	360			2	3	4	4	3						16
	39.	GEN. APPL. MODULE	65	100	14 x 51	30,000	0			2	3	2	3	2	3		3	1		19
	40.	DED. SCI. & RES. MOD. ASTR.	55	200	14 x 54	29,500	360						1	3	4	5	4	5	5	27
	41.	DED. APPL. MOD. - EARTH OBS.	75	100	14 x 51	22,500	0						2	2	2	2	2	3	4	17
		PALLET TYPE MODULE																		
	42.	EARTH OBSERVATION	90	125	14 x 37	6,000	171		1	1	2									4
	43.	BIOLOGICAL RESEARCH	28.5	200	14 x 37	4,300	360	1												1
	44.	ASTRONOMY	28.5	200	14 x 37	5,700	360		2	2	2	1								7
	45.	FLUID MANAGEMENT	28.5	200	14 x 37	7,100	360		1			1								2
	46.	TELEOPERATOR	28.5	200	14 x 37	5,000	360		1											1
	47.	MANNED WORK PLATFORM	28.5	200	14 x 37	6,700	360			1										1
	48.	LARGE TELESCOPE MIRROR TEST	28.5	200	14 x 37	13,000	360	1												1
	49.	ASTRONAUT MAN. UNIT (AMU)	28.5	200	14 x 37	3,800	360		1											1
PLANETARY	50	VIKING	30	1.52 AU	10 x 12	7,700	15,400	1		1										2
	51	MARS SAMPLE RETURN	30	1.52 AU	14 x 22.5	22,000	15,400												2	2
	52	VENUS EXPLORER	30	.723 AU	5 x 12	1,000	13,400		1											1
	53	VENUS RADAR MAPPING	30	.723 AU	10 x 12	7,900	13,400				1									1
	54	VENUS EXPLORER LANDER	30	.723 AU	10 x 15	7,300	13,400							1			1			2
	55	JUPITER PIONEER ORBITER	30	5.20 AU	10 x 15	900	22,700				2									2
	56	GRAND TOUR (JUN)	30	30.06 AU	10 x 12	1,500	25,900	2												2
	57	JUPITER TOPS ORBITER/PROBE	30	5.20 AU	10 x 15	3,300	22,700							1		1				2
	58	URANUS TOPS ORBITER/PROBE	30	19.18 AU	10 x 15	3,700	24,000								1			1		2
	59	ASTEROID SURVEY	30	2.9 AU	10 x 35	27,000	13,400						1							1
	60	COMET RENDEZVOUS	30	.34 AU	10 x 35	24,000	13,400				1			1						2
SPACE STATION	61	STATION MODULES - CORE	55	270	14 x 40	20,000	592			1			1	1	3	2				8
	62	STATION MODULES - OTHERS	55	270	14 x 30	20,000	592			5				3						8
	63	CREW CARGO	55	270	14 x 30	20,000	592			1	6	6	6	6	8	8	8	8	8	65
	64	PHYSICS LAB	55	270	14 x 32	22,000	592					1					1			2
	65	COSMIC RAY LAB	55	270	14 x 52	30,000	592										1			1
	66	LIFE SCIENCE LAB	55	270	14 x 58	33,000	592			1		1		1					1	4
	67	EARTH OBSERVATIONS LAB	55	270	14 x 45	25,000	592			1		1		1					1	4
	68	COMM/NAVIGATION LAB	55	270	14 x 38	19,000	592					1		1					1	3
	69	SPACE MANUFACTURING LAB	55	270	14 x 45	25,000	592												1	1
NON-NASA	70	COMSAT SATELLITES	0	19300	6.5 x 12	1,420	14,100	2	1	1		2	1	1			2	1		11
	71	U.S. DOMESTIC COMM	0	19300	10 x 19	2,145	14,100	1	2	1	1	2	2	2	2	2	2	2	2	21
	72	FOREIGN DOMESTIC COMM.	28.5	19300	4 x 12	1,000	13,000		2	6	2	2			4	5	2	1	2	26
	73	NAV & TRAFFIC CONTROL	29	30000 x 16000	5 x 8	700	13,948	3	1	2		1		1		1		1		10
	74	NAV & TRAFFIC CONTROL	5	19300	5 x 8	700	13,400		1	1		1		1		1		1		6
	75	TOS METEOROLOGICAL	100.7	700	5 x 6	1,000	1,940	1	1	1	1	1	1	1	1	1	1	1	1	12
	76	SYNC METEOROLOGICAL	0	19300	5 x 8	1,000	14,100	1	1	1	1	1	1	1	1	1	1	1	1	12
	77	POLAR EARTH RESOURCES	99.15	500	12 x 15	2,500	1,330	4		4		4		4				6		22
	78	SYNCH EARTH RESOURCES	0	19300	6 x 6	1,000	14,100							4			4			8
TOTAL								31	33	55	46	54	46	62	51	57	58	56	50	599

① THEORETICAL MINIMUM, ONE-WAY, POINT-TO-POINT ΔV

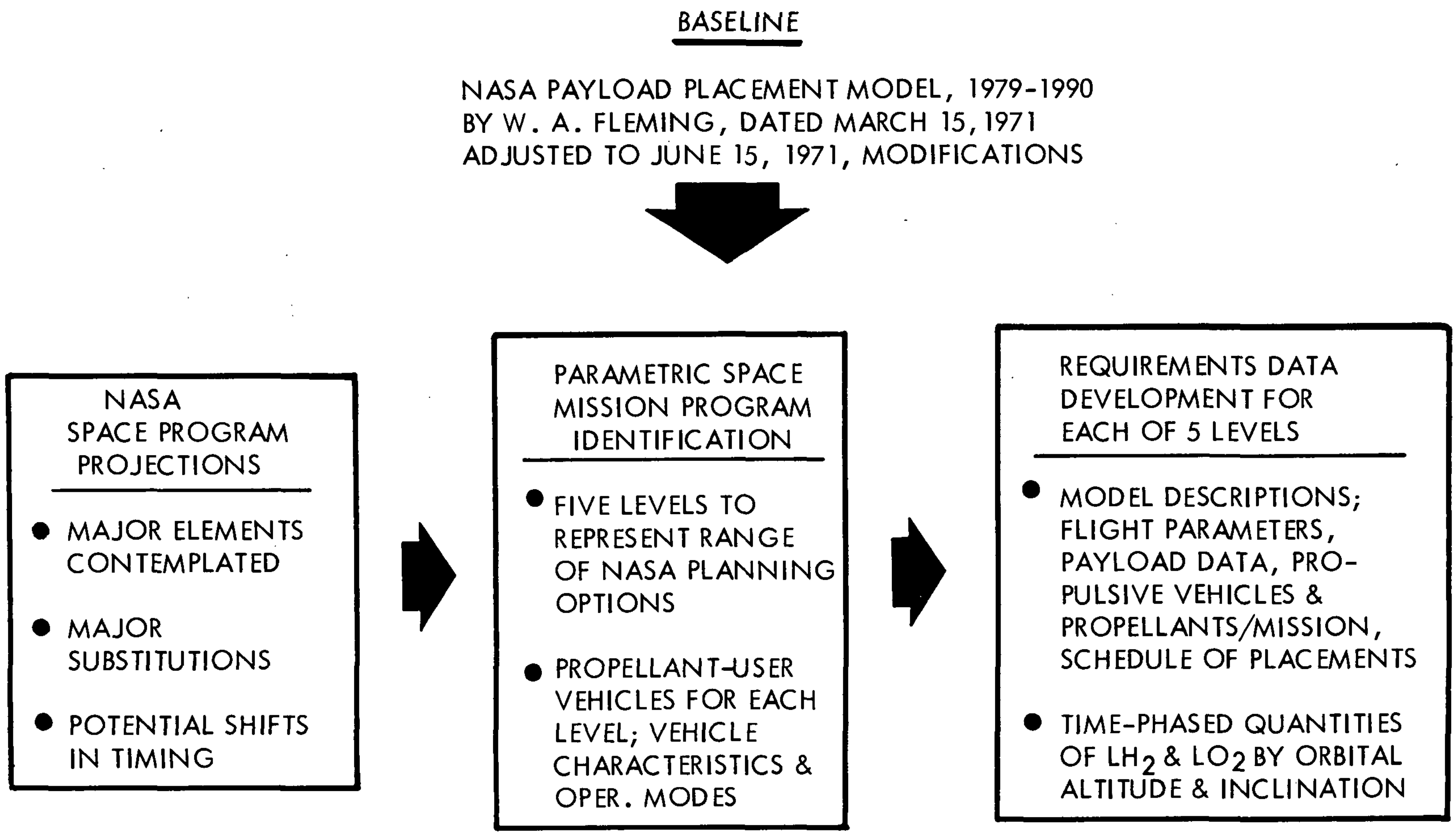


Figure 3.1-1 Approach to Identification of NASA Space Program Requirements

d. Exploration
e. Social
f. International Relations

NASA planning documentation relates the development of planning options to the Space Task Group report by means of the following planning concepts:

a. Increasing returns in science, engineering and applications commensurate with investment costs.

b. Pursuit of the principles of commonality, reusability and economy through the efficient development, management and operation of manned space systems.

c. Continued exploration of the solar system.....

The main thrust of the NASA contemplated mission program is directed to the implementation of Planning Concept a. To this end the contemplated program is primarily performed in earth orbit and contains major earth-oriented missions. These missions are performed with unmanned spacecraft, with man-tended spacecraft/experiments, through a program of sorties with the space shuttle, and by means of a long duration space station.

Planning Concept b is implemented by means of the space shuttle program. Transportation system economies are obtained directly as a result of reusability. Additionally, the space shuttle, by being able to retrieve and return spacecraft and other payloads to earth for refurbishment and reuse, further supports Planning Concept b. The space program models for the ISPLS study, therefore, are based totally on the use of the space shuttle as the earth-to-earth orbit space transportation system.

Whereas earlier NASA planning included a possible manned Mars expedition in the 1980's, this expedition is now considered a long-range goal. Consequently, the NASA plan for exploration of the solar system in the 1979-1990 time period of the ISPLS study utilizes unmanned planetary spacecraft and is supported by remote observations from earth orbit and ground-based studies.

Major elements in the NASA contemplated space program are:

a. Space Shuttle - The space shuttle, as noted above, is to be the earth-to-orbit transportation system for the 1980's and beyond. The ISPLS study assumes that all missions in the contemplated mission program options will utilize the space shuttle. This assumes full operational capability in early 1979. The baseline shuttle is defined as having a clear cargo bay 15 feet in diameter and 60 feet long. Payload performance capability is 65,000 pounds to a 100-nautical mile circular orbit at 28.5 degrees, 40,000 pounds to a 100-nautical mile circular polar orbit, and 25,000 pounds to a space station at 270-nautical mile circular orbit at 55 degrees inclination. The shuttle is described more fully in a later section.

b. Space Station - Reference 3.1-2 identifies the modular space station approach as embodying two time-phased capability plateaus: an initial 6-man station for 5 years of operation followed by growth to a 12-man station. The initial modular space station provides the capability to operate at least two research and applications modules (RAM) in either an attached or detached operating mode, as well as internal general-purpose laboratories with capability to conduct multi-discipline carry-on experiments. The full growth station adds crew/lab modules and a half-core module to provide four ports for RAM or tug support.

   The space station electrical power system utilizes a solar array and regenerative fuel cell system. The life support subsystem utilizes a closed oxygen and water cycle concept. The reaction control system utilizes gaseous hydrogen and oxygen supplied by water electrolysis (ECLSS). Water, re-supplied on cargo flights, is the only consumable required for these integrated assemblies. As a result, the space station does not pose requirements for LH_2 or LO_2 in earth orbit.

c. Space Base - Options considered by the Space Task Group include 24-, 50- and 100-man space base concepts. These concepts are not a part of the contemplated mission program for the 1979-1990 time period as outlined by NASA Central Planning. Consequently, the space base is not included as a major element in this Identification of NASA Space Program Requirements.

d. Orbiting Lunar Station - A concept for an orbiting lunar station was developed in a Phase A feasibility and definition study, Reference 3.1-3. The orbiting lunar station conceptually provides for the performance of an experiment program in lunar orbit and supports the accomplishment of lunar surface scientific and exploration objectives. The orbiting lunar station is not included in NASA's baseline contemplated space mission program for the 1979-1990 period. Manned lunar exploration options, however, are included in the ISPLS Parametric Space Program. These are discussed in Appendix A.

e. Lunar Surface Base - The lunar surface base is a potential space program element which conceptually provides for scientific and exploration activities on the lunar surface by a crew of up to 12 men. A lunar surface base study performed under contract to the NASA-MSFC is reported in Reference 3.1-4. The configuration includes a main shelter, major science elements and surface mobility systems. The mission program requires an interorbital shuttle to transport heavy payloads between low earth orbit and lunar orbit, and lunar landing tugs to transport payloads between lunar orbit and the lunar surface. Logistics support of the lunar surface base as an optional addition to the baseline NASA contemplated space program is also reviewed in Appendix A.

f. Cislunar Shuttle - Two major alternates for the cislunar shuttle are: The reusable nuclear shuttle (RNS) and the chemical interorbital shuttle (CIS). It is expected that only one of these alternate vehicles would be developed to support a manned lunar

program. The cislunar shuttle also has the capability to transport heavy payloads between low earth orbit and geosynchronous orbit. However, no requirement is currently projected for this heavy geosynchronous capability. High energy/high payload planetary exploration missions may require the injection capability of an interorbital shuttle. These potential missions are reviewed in Appendix A. Descriptions of the RNS and CIS alternates are presented in Appendix B.

g. Space Tug - A reusable space tug which operates essentially as an upper stage to the space shuttle is a very important element of the NASA contemplated space program. The space tug concept features enhanced mission effectiveness through payload performance, placement and retrieval capability and operational flexibility. The concept features reduced recurring costs through reusability. Two major alternatives for consideration in this study are: (1) the ground-based and (2) the space-based tug which requires resupply of LH_2 and LO_2 in orbit. These tug alternates are reviewed in Appendix B.

These contemplated space program elements and major alternatives are utilized in the ISPLS study in conjunction with a payload placement model supplied by the NASA to construct the Parametric Space Program model presented in Section 3.2.

3.2 ISPLS SPACE TRAFFIC MODELS

In the ISPLS study, space program alternatives have been introduced in the requirements area so that the Overall Systems/Operations Analysis can be performed across a range of NASA planning options. These alternatives include:

- °Space program alternatives
- °Space vehicle alternatives
- °Vehicle operational mode alternatives

To the degree that the alternatives selected encompass future plans, the study results should have long-term applicability for the NASA.

Space program alternatives are presented first. Space vehicle and vehicle basing alternatives are presented next. Combined space mission/vehicle program models which together make up the parametric space programs conclude this section.

3.2.1 Parametric Space Program Alternatives

Five distinct payload placement/mission programs representing five alternative levels of space program activity have been developed. In ascending order of activity, these are identified as Program Levels A, B, C, D and E. The updated NASA Payload Placement Model, Table 3.1-1, is defined as the ISPLS baseline program and is incorporated as Program Level C. This baseline model has been updated to include more comprehensive definition of the magnetosphere explorer missions, Numbers 3, 4 and 5, and by deletion of a planetary relay satellite mission, Number 37.

The term "placements" herein includes:

- °delivering payloads to their operational orbits and deploying them
- °retrieving payloads
- °injecting payloads for earth-escape and planetary missions
- °space shuttle sortie missions
- °the launch of space station modules and labs, and resupply and crew rotation flights

The total number of placements over the 12-year mission program is 599, an average of 50 per year. Ten of these are payload retrieval missions.

Definition of the alternative program levels was accomplished by the NASA and the NR Space Division jointly. Subsequent to the initial definitions, revisions were introduced to the D- and E-level programs by the NASA.

Table 3.2.1-1 shows how the five space program levels relate and in what respect they differ. Differences between the lower mission program levels are confined to the earth orbital area. With the exception of space station missions, Program Level B contains 3/4 of the flights in Level C and Program Level A contains half the flights in Level C. In Program Level B the space station IOC is deferred one year. In the minimum mission program, Level A, there is no space station in the 1979-1990 period.

Program Levels D and E retain the earth orbital program of the updated Fleming Model and add NASA planetary relay satellites and a total of 96 non-NASA communications and broadcast satellites. This represents a large potential increase in space applications.

In the planetary area a Saturn orbiter is added to the baseline planetary program at Levels D and E. Additionally, Program Level E incorporates five high-energy, heavy-payload planetary exploration missions. This augmentation of the planetary program, which requires the use of an RNS or, alternately, a CIS, is the only mission difference between Program Levels D and E.

Both Program Levels D and E incorporate the same lunar program. This lunar program contains two phases : (1) automated lunar missions with orbiters and landers containing remotely operated rovers, and (2) a follow-up manned lunar program. The manned lunar program produces a step-increase in orbital propellant requirements.

Table 3.2.1-2, the Parametric Space Program, lists all the placements and retrievals in each of the five program levels. Missions designated by the numerals 1 through 78 include the ones contained in the updated NASA Payload List (Fleming Model) of Table 3.1-1 and those subsequently added by NASA (Numbers 37, 60-3, 78-2, 78-3 and 78-4). Alphanumeric symbols have been used to designate missions added by the contractor. Missions L-1 through L-4 identify automated and manned lunar missions which are introduced in Program Level D; and missions P-2, P-3 and P-4 identify augmented planetary missions introduced in Program Level E.

Table 3.2.1-1 Program Level Composition Guide ~ Missions

MISSION AREA	SPACE PROGRAM LEVEL				
	A	B	C	D	E
EARTH ORBITAL	HALF OF FLEMING	3/4 OF FLEMING	FLEMING	FLEMING PLUS: PLANETARY RELAY SATS (9) COMMUN. SATS, GENERAL (48) BROADCAST SATS, INDIV. (24) BROADCAST SATS, COMMUN(24)	
SPACE STATION	NO STATION	STATION '82	STATION '81	STATION '81	STATION '81
PLANETARY	FLEMING	FLEMING	FLEMING	FLEMING PLUS SATURN ORBITER	FLEMING PLUS SATURN ORBITER INCORPORATE 5 AUGMENTED PLANETARY MISSIONS
LUNAR	NONE	NONE	NONE	AUTOMATED LUNAR PROGRAM PER SPACE SCIENCE BOARD '70 SUMMER STUDY, OPTION 1: 5 ORBITERS, '80-'84 5 LANDERS, '80-'84 MANNED LUNAR PROGRAM: 2 FLIGHTS PER YEAR '86-'90	

Table 3.2.1-2 Parametric Space Program (1979-1990)
Distribution of Flights

CATEGORY	NO.	TITLE			SPACE PROGRAM LEVEL A	B	C	D	E
					NUMBER OF PLACEMENTS				
PHYSICS & ASTRONOMY	1*	ASTRONOMY EXPLORER		A	7	11	15	15	15
	2	RADIO EXPLORER		B	4	6	9	9	9
	3	MAGNETOSPHERE EXPLORER		LOW	6	9	12	12	12
	4	MAGNETOSPHERE EXPLORER		MEDIUM	6	9	12	12	12
	5	MAGNETOSPHERE EXPLORER		HIGH	6	9	12	12	12
	6*	ORBITING SOLAR OBSERVATORY			1	1	1	1	1
	7*	GRAVITY/RELATIVITY EXPERIMENT		C,E	1	2	2	2	2
	8	GRAVITY/RELATIVITY EXPERIMENT		B,D	1	2	2	2	2
	9	RADIO INTERFEROMETER		SYNC	1	1	1	1	1
	10	SOLAR ORBIT PAIR		SYNC	1	2	2	2	2
	11	SOLAR ORBIT PAIR		1.0 AU	1	2	2	2	2
	12	OPTICAL INTERFEROMETER		PAIR	2	2	2	2	2
	13*	HEAO & HIGH ENERGY SOLAR ASTRONOMY			4	4	6	6	6
	14*	REVISITS			12	16	22	22	22
	15*	LST (STAR) & (RAM)			2	2	3	3	3
	16*	LST REVISITS			8	12	17	17	17
	17*	LARGE SOLAR OBSERVATORY			1	2	3	3	3
	18*	LARGE SOLAR OBSERVATORY REVISITS			5	9	13	13	13
	19*	LARGE RADIO OBSERVATORY			1	1	1	1	1
	20*	LARGE RADIO OBSERVATORY REVISITS			2	6	10	10	10
EARTH OBSERVATIONS	21	POLAR EARTH OBSERVATIONS SATELLITE		R&D	6	9	12	12	12
	22	SYNCHRONOUS EARTH OBSERVATIONS SATELLITE		R&D	3	4	6	6	6
	23	EARTH PHYSICS SATELLITE		R&D	3	5	7	7	7
	24	SYNCHRONOUS METEOROLOGICAL SATELLITE		SYS DEMO	1	2	2	2	2
	25	TIROS		SYS DEMO	2	2	3	3	3
	26	POLAR EARTH RESOURCES SATELLITE		SYS DEMO	3	5	6	6	6
	27	SYNCHRONOUS EARTH RESOURCES SATELLITE		SYS DEMO	4	5	7	7	7
COMMUNICATION/ NAVIGATION	28	APPLICATIONS TECHNOLOGY SATELLITE	SYNC	R&D	4	5	7	7	7
	29	SMALL APPLICATIONS SATELLITE	SYNC	R&D	6	9	12	12	12
	30	SMALL APPLICATIONS SATELLITE	POLAR	R&D	6	9	12	12	12
	31	COOPERATIVE APPLICATIONS	SYNC	R&D	2	2	2	2	2
	32	COOPERATIVE APPLICATIONS	POLAR	R&D	2	2	2	2	2
	33	MEDICAL NETWORK SATELLITE	SYNC	SYS DEMO	2	2	2	2	2
	34	EDUCATION BROADCAST SATELLITE	SYNC	SYS DEMO	2	2	2	2	2
	35	FOLLOW-ON SYSTEM DEMONSTRATION	SYNC	SYS DEMO	6	13	20	20	20
	36	TRACKING AND DATA RELAY	SYNC	OPER	5	7	10	10	10
	37	PLANETARY RELAY SATELLITE	SYNC	OPER	-	-	-	9	9
SORTIES	38*	GENERAL SCIENCE RESEARCH MODULE			7	12	16	16	16
	39*	GENERAL APPLICATIONS MODULE			9	14	19	19	19
	40*	DEDICATED SCIENCE AND RESEARCH MODULAR ASTRONOMY			13	20	27	27	27
	41*	DEDICATED APPLICATIONS MODULE - EARTH OBSERVATION			8	12	17	17	17
	42*	EARTH OBSERVATION			2	3	4	4	4
	43*	BIOLOGICAL RESEARCH			1	1	1	1	1
	44*	ASTRONOMY			4	5	7	7	7
	45*	FLUID MANAGEMENT			1	2	2	2	2
	46*	TELEOPERATOR			1	1	1	1	1
	47*	MANNED WORK PLATFORM			1	1	1	1	1
	48*	LARGE TELESCOPE MIRROR TEST			1	1	1	1	1
	49*	ASTRONAUT MANEUVERING UNIT (AMU)			1	1	1	1	1

*NO PAYLOAD PROPULSIVE STAGE

Table 3.2.1-2 Parametric Space Program (1979-1990)
Distribution of Flights (Part 2)

REVISED 10/31/71

CATEGORY	NO.	TITLE		SPACE PROGRAM LEVEL				
				A	B	C	D	E
PLANETARY	50	VIKING		2	2	2	2	2
	51	MARS SAMPLE RETURN		2	2	2	2	
	52	VENUS EXPLORER		1	1	1	1	1
	53	VENUS RADAR MAPPING		1	1	1	1	1
	54	VENUS EXPLORER LANDER		2	2	2	2	
	55	JUPITER PIONEER ORBITER		2	2	2	2	2
	56	GRAND TOUR (JUN)		2	2	2	2	2
	57	JUPITER TOPS ORBITER/PROBE		2	2	2	2	1
	58	URANUS TOPS ORBITER/PROBE		2	2	2	2	2
	59	ASTEROID SURVEY		1	1	1	1	1
	60	COMET RENDEZVOUS		2	2	2	2	2
	60-3	SATURN ORBITER					1	1
	P-2	VENUS SURFACE SAMPLE & RETURN	RNS/CIS					1
	P-3	MARS SURFACE SAMPLE & RETURN	RNS/CIS					2
	P-4	JUPITER ORBITERS/PROBES & SATELITTE LANDERS	RNS/CIS					2
SPACE STATION	61*	STATION MODULES CORE			8	8	8	8
	62*	STATION MODULES - OTHERS			8	8	8	8
	63*	CREW CARGO			57	65	65	65
	64*	PHYSICS LAB			1	2	2	2
	65*	COSMIC RAY LAB			1	1	1	1
	66*	LIFE SCIENCE LAB			2	4	4	4
	67*	EARTH OBSERVATIONS LAB			2	4	4	4
	68*	COMMUNICATIONS/NAVIGATION LAB			1	3	3	3
	69*	SPACE MANUFACTURING LAB				1	1	1
NON-NASA	70	COMSAT SATELLITES	SYNC	6	8	11	11	11
	71	U.S. DOMESTIC COMMUNICATIONS	SYNC	10	16	21	21	21
	72	FOREIGN DOMESTIC COMMUNICATIONS	SYNC	13	19	26	26	26
	73	NAVIGATION & TRAFFIC CONTROL		5	8	10	10	10
	74	NAVIGATION & TRAFFIC CONTROL	SYNC	3	5	6	6	6
	75	TOS METEOROTOGICAL		6	9	12	12	12
	76	SYNCHRONOUS METEOROLOGICAL	SYNC	6	9	12	12	12
	77	POLAR EARTH RESOURCES		11	16	22	22	22
	78	SYNCHRONOUS EARTH RESOURCES	SYNC	4	6	8	8	8
	78-2	COMM SATS IN GENERAL					48	48
	78-3	BROADCAST SAT INDIVIDUAL RECEPTION					24	24
	78-4	BROADCAST SAT COMMUNITY RECEPTION					24	24
LUNAR	L-1	AUTOMATED LUNAR PROGRAM ORBITERS					5	5
	L-2	AUTOMATED LUNAR PROGRAM LANDERS					5	5
	L-3	MANNED SORTIE-CLASS MISSIONS	RNS/CIS				6	6
	L-4	POST-SORTIE SURFACE OPERATIONS	RNS/CIS				4	4
TOTAL		1979-1990 TWELVE-YEAR TOTAL		261	459	599	725	725

* NO PAYLOAD PROPULSIVE STAGE

A number of payload placements and retrievals are performed by the space shuttle all-the-way, i.e., no payload propulsive stage is required. These missions, which do not contribute to "in-space" propellant requirements, are identified by asterisks (*) alongside their mission numbers. (It should be noted that, for the purpose of this study, "in-space" propellant requirements were considered to be only those imposed by payload propulsive stages, both ground-based and space-based. Shuttle orbiter or ESS propellant requirements were not included since they are satisfied by GSE.)

The alternate space program levels introduced by means of Tables 3.2.1-1 and -2 are summarized with regard to number of placements and by mission category (physics and astronomy, earth observations, etc.) in Figure 3.2.1-1. The shaded portion of each column in this figure represents the payload placements which impose in-space propellant requirements; these are summarized by the numbers in parenthesis at the top of each column. The unshaded portions represent all space station, all sortie, and part of the physics and astronomy missions which do not contribute to in-space propellant requirements and which are identified by asterisks in Table 3.2.1-2. The larger number at the top of each column is the sum of all the placements and retrievals in each program level over the 12-year period 1979-1990. It is seen that the activity level increases by a factor of almost three between Program Levels A and D. Figure 3.2.1-2 presents summary data concerning the lunar missions, L-1 through L-4, added in Program Levels D and E, and the five augmented planetary missions, P-2, P-3 and P-4, introduced in Program Level E in place of five less demanding missions.

The renewed lunar mission program begins in 1980 with a 10-flight automated lunar program involving both orbiters and landers with rovers and sample return. This is the "Option 1" program suggested by the Space Science Board in its 1970 summer study - but deferred here by two years. A reusable tug or expendable stages would provide translunar injection of the automated spacecraft.

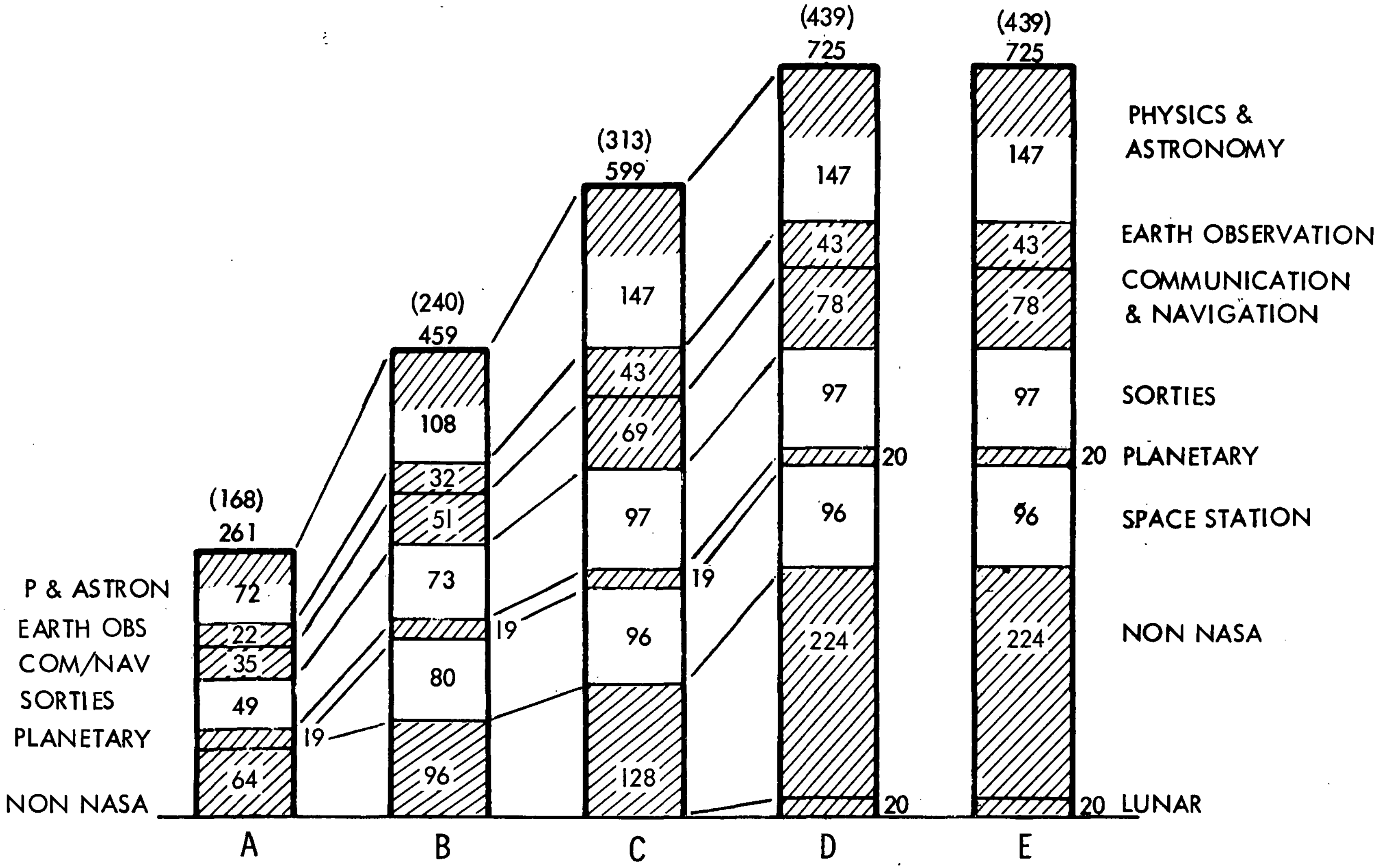
The conceptual manned lunar program contains two phases: (1) an exploration/transition phase involving sortie-type missions, and (2) an applications phase. The latter would utilize support systems like those described in the Lunar Surface Base Study. The manned lunar program requires either an RNS or CIS at two flights per year beginning in 1986.

The augmented planetary program contains three inner planet missions which perform surface sample and return operations. Two heavy Jupiter missions are also projected to yield very high scientific return. All five missions utilize either an RNS or CIS for transplanetary injection, starting in 1984.

More detailed information concerning the lunar and planetary program additions is presented in Appendix A. Also included in Appendix A is a summary of the NASA additions to the baseline Fleming Model, Program Level C.

3.2.2 Space Vehicle Alternatives (Propellant User Elements)

The alternate payload placement models, which represent alternate levels of space program activities, have been described in part by the various levels



( ) DENOTES NUMBER OF MISSIONS INCLUDED IN PROPELLANT REQUIREMENT ANALYSIS

Figure 3.2.1-1 Payload Placements Summary, Parametric Space Program, 1979-1990

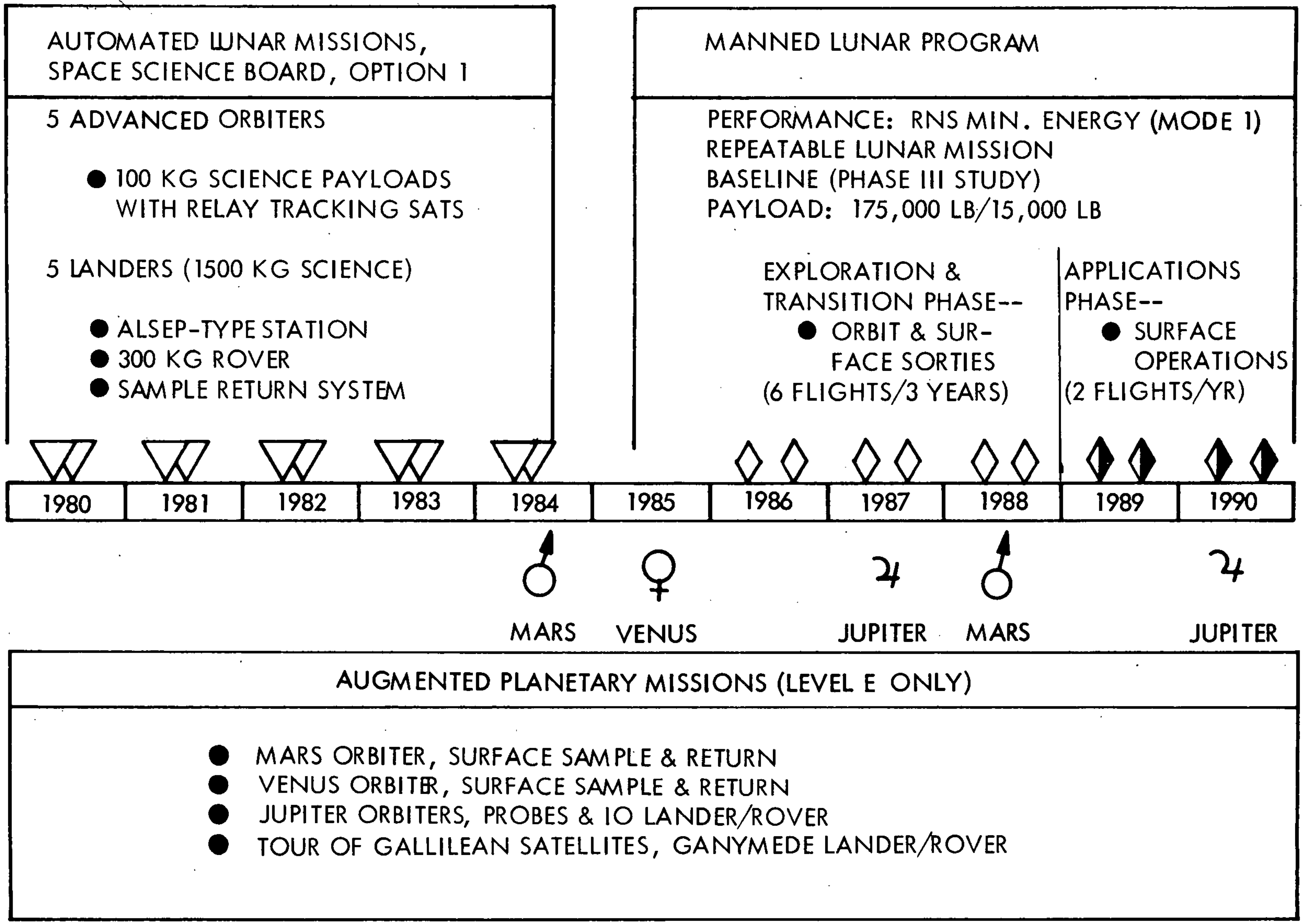


Figure 3.2.1-2 Lunar and Augmented Planetary Missions, Program Levels D and E

of traffic and makeup of missions. They are also described in part by the payload propulsive stages which are employed at each specific level.

Payload propulsive stages for scientific payload placements include both ground-based and space-based vehicles. Physical characteristics of these stages are summarized in Figure 3.2.2-1.

3.2.2.1 Space-Based Payload Propulsive Stages

The space-based propulsive stages defined for this study include the space-based tug, CIS, and RNS. All three vehicles are reusable, in-space propellant receivers.

The space-based tug identified for this study is represented by the single-stage design developed during a pre-phase A study performed by the NR Space Division for the NASA-MSC. Its characteristics are described by Figures 3.2.2-2 and 3.2.2-3. The former of these figures includes modifications from the design evolved during the tug study to the extent necessary to make the vehicle compatible with the propellant transfer provisions of candidate in-space logistics systems. The need for these modifications is discussed in another section of this report; but the baseline tug performance of Figure 3.2.2-3 has not been adjusted for the effect of these modifications.

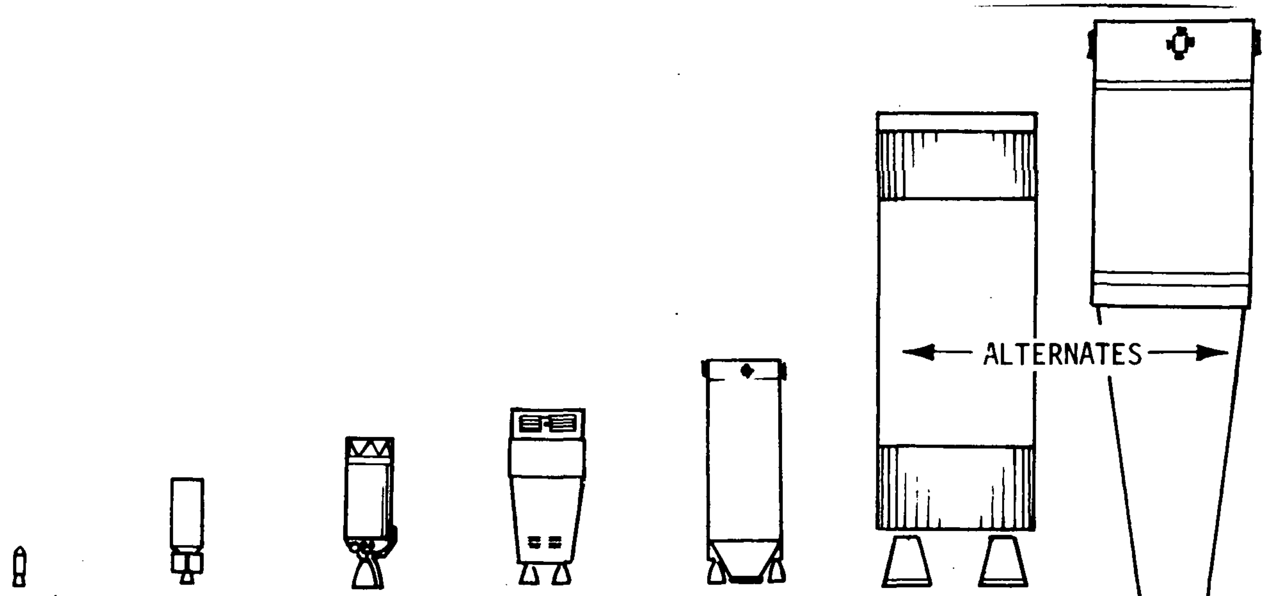
The RNS and CIS are major alternatives. In accordance with the ISPLS study ground rules, the vehicle characteristics used represent large tank designs from the "Nuclear Flight System Definition Study," Contract NAS8-24975, and the "S-II Stage Interorbital Shuttle Capability Analysis," Contract NAS7-200 (Change Order 2021). Specific physical and performance characteristics for these two vehicles are shown in Figures 3.2.2-4 through 3.2.2-8. It should be noted that the CIS propellant loading permits performance of the same lunar missions as with the RNS using a repeatable, minimum-energy, direct flight mode.

Characteristics of these payload propulsive stages are reviewed in more detail in Appendix B.

3.2.2.2 Ground-Based Payload Propulsive Stages

The ground-based propulsive stages defined for this study include the FW-4S Derivative "Kick Stage", Agena, Centaur, and ground-based tug. The FW-4S, Agena, and Centaur are expendable (nonreusable) vehicles operating on solid, hypergolic, and cryogenic propellants, respectively. Physical and performance characteristics of these vehicles are shown in Figures 3.2.2-9 through 3.2.2-12. The ground-based tug, like its space-based counterpart, is a reusable vehicle operating on cryogenic propellants. The ground-based tug characteristics, shown in Figures 3.2.2-13 and 3.2.2-14, are those defined by the NR Space Division for a single stage orbit-to-orbit shuttle (OOS) studied for the USAF.

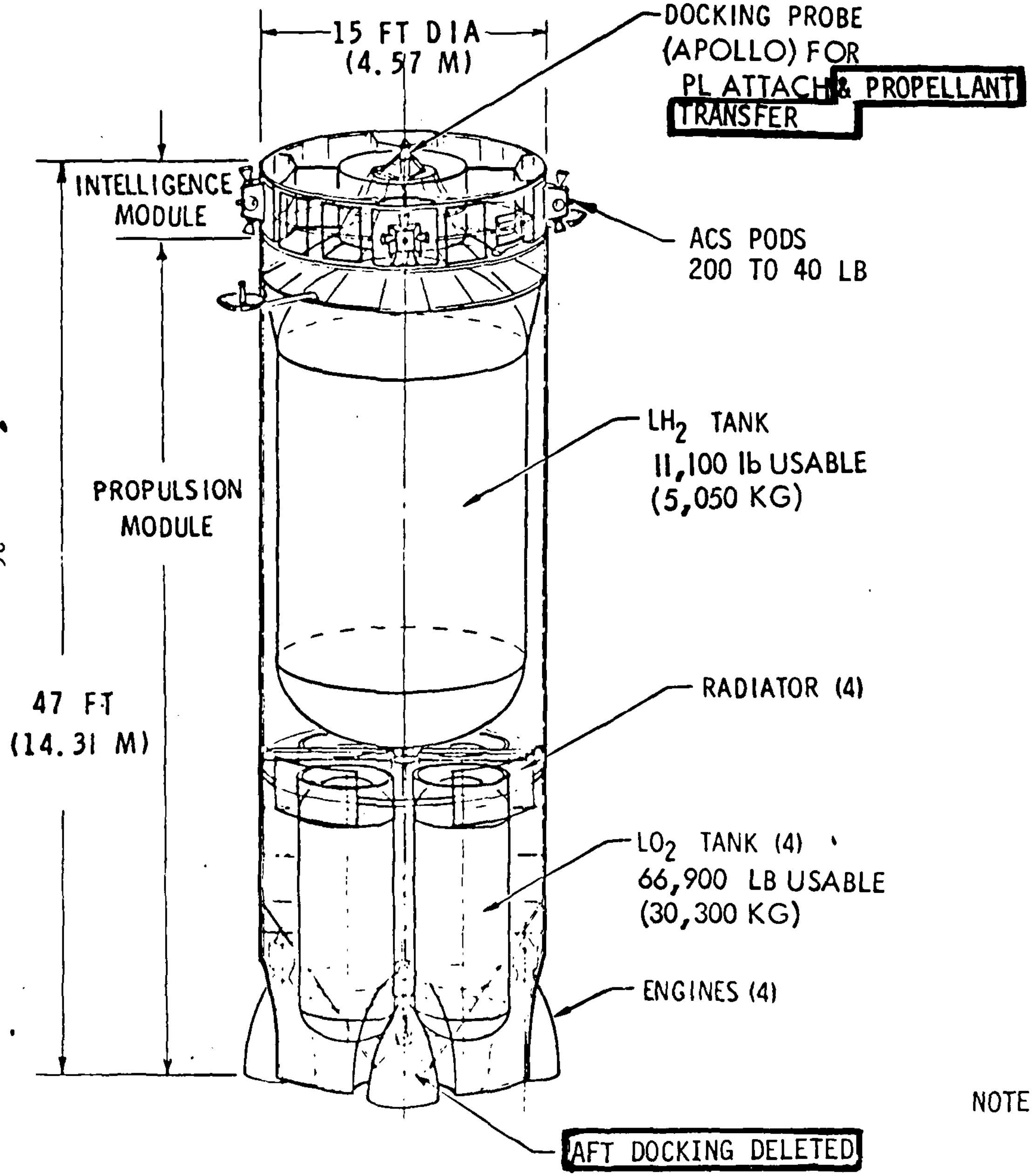
A more detailed review of these ground-based payload propulsive stages may be found in Appendix B.



CHARACTERISTICS	FW4S	AGENA	CENTAUR	TUG (OOS)	SPACE TUG	CIS	RNS
	GROUND-BASED				SPACE-BASED		
LENGTH - FT	6.8	20	31.5	36	47	100	194
DIAMETER - FT	2.1	5	10	15	15	33	33
WEIGHTS - LB							
GROSS	860	15000	35,300	67,500	83,400	1,095,000	377,000
PROPELLANT	—	13600	30,200	60,200	73,200	990,000*	300,000*
EXPENDABLE	X	X	X				
REUSABLE				X	X	X	X
IN SPACE PROP. RECEIVER					X	X	X

*LUNAR MISSION MODE 1 REQUIREMENTS

Figure 3.2.2-1 Payload Propulsive Stages



ISPLSS BASELINE TUG

- HAS BASIC MISSION CAPABILITIES OF PAYLOAD INTERFACE, PAYLOAD PLACEMENT AND SPACE BASED ORBITAL OPERATIONS (FURTHER DEFINITIONS AS GIVEN IN SD71-292, CONFIGURATION 1). ADDITIONAL CAPABILITIES OF PERTINANCE TO PROPELLANT LOGISTICS ARE GIVEN BELOW.
- IS ACTIVE VEHICLE IN RENDEZVOUS & DOCKING; DOCKING FIXTURE NEEDS ACCURATE INDEXING FOR TRANSLINE ALIGNMENT (NOT PROVIDED BY APOLLO FIXTURE).
- HAS PROPELLANT FILL LINE RECEPTACLES AT FWD END; MUST RELY ON PROPELLANT SUPPLIER FOR LINE INTERCONNECT MECHANISM.
- PRESUMABLY HAS GAS RETURN & VENT LINES, GAGING ETC. DESIGNED TO RECEIVE PROPELLANTS WITH SETTLING TOWARD AFT END.
- HAS NO PROVISIONS TO SUPPLY PROPELLANTS
- COULD PROVIDE THRUST FOR ROTATIONAL SETTLING OF PROPELLANT.
- COULD NOT THRUST FOR LINEAR PROPELLANT SETTLING (ACS THRUST TOO HIGH).
- COULD SUPPLY POWER FOR MONITORING, VAVLE ACTUATION & GENERAL HOUSEKEEPING REQUIREMENTS OF A LOGISTICS TANK, BUT NOT TO RUN THE COMPRESSORS DURING PROPELLANT TRANSFER.

NOTE: ITEMS ENCLOSED BY A HEAVY LINE ( ) INDICATE ASSUMED DEVIATIONS FROM TUG STUDY TO MAKE A MORE REALISTIC TUG CONFIGURATION FOR THE ISPLS BASELINE TUG

Figure 3.2.2-2 Space-Based Reusable Tug Concept

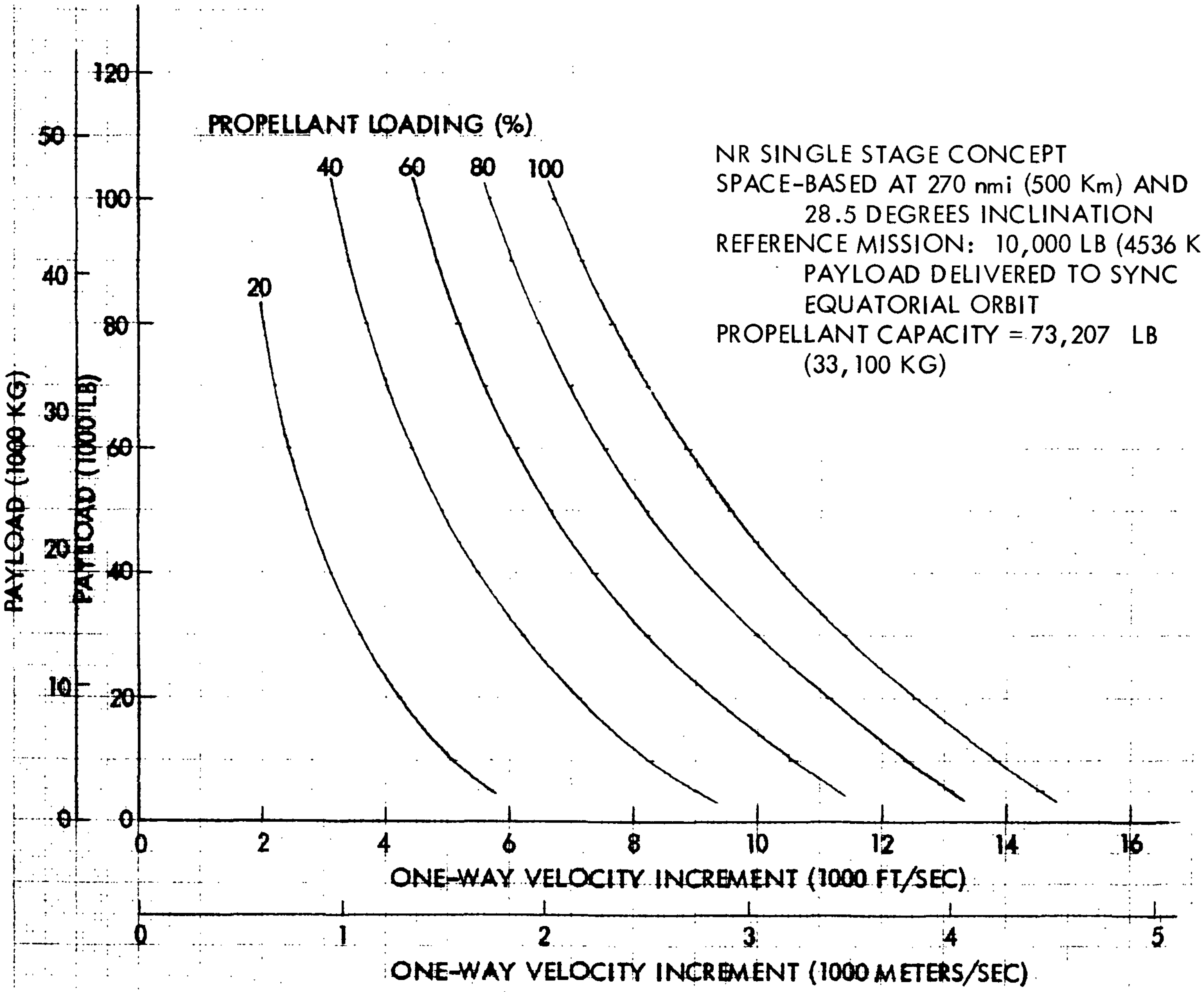


Figure 3.2.2-3 Reusable Tug Performance Characteristics

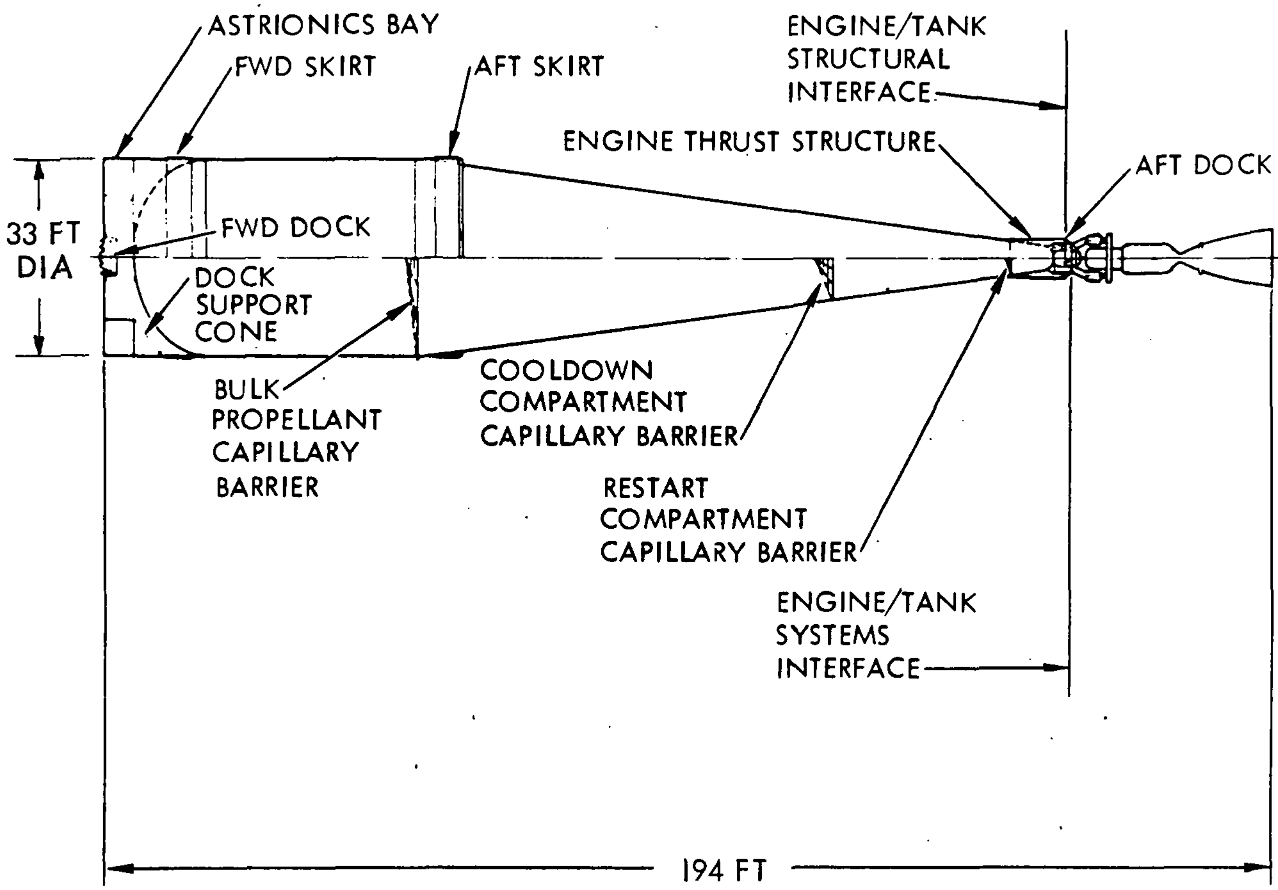
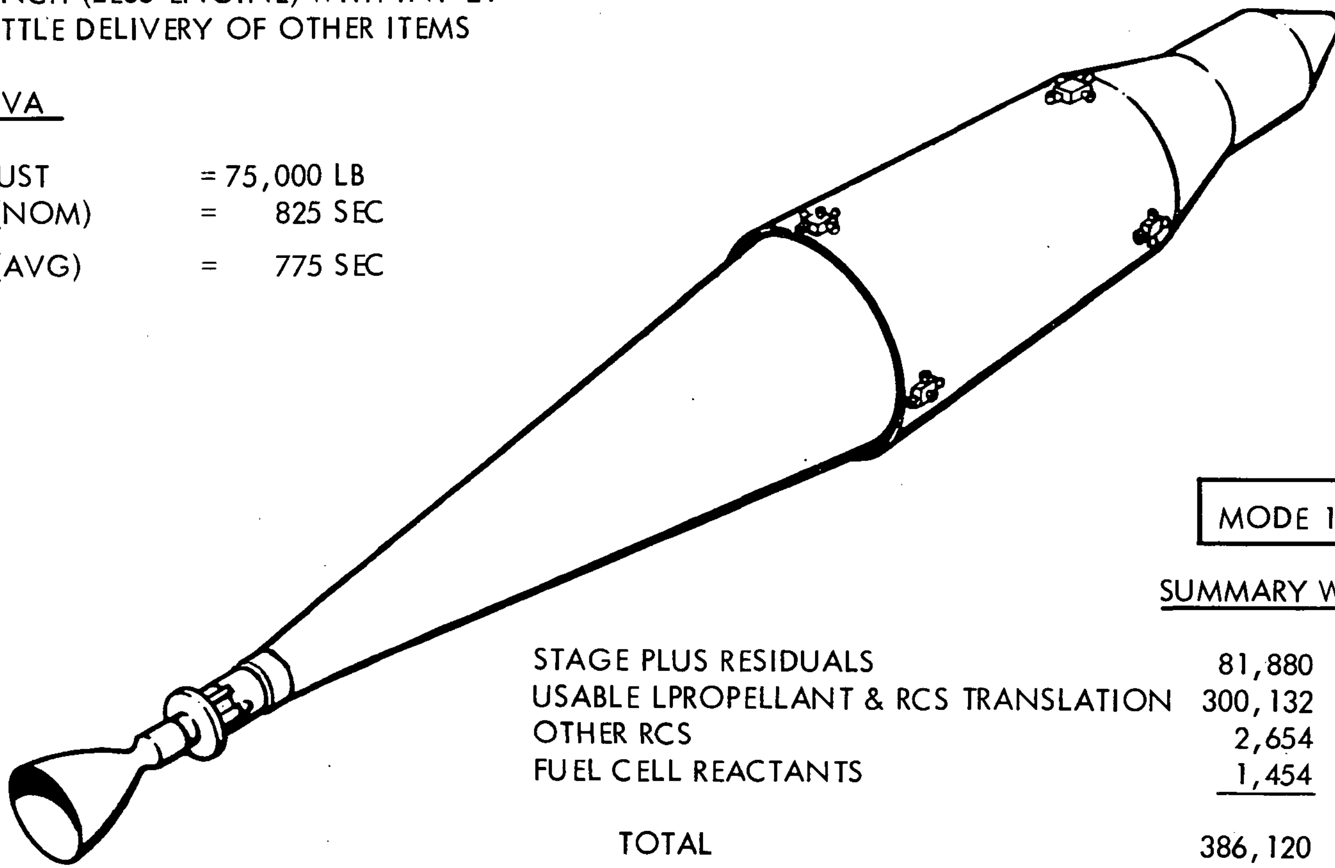


Figure 3.2.2-4 Reusable Nuclear Shuttle Concept

33 FT DIA MAIN LH_2 TANK
1974 TECHNOLOGY; 3 YR OPER. LIFE OR 10 REUSES
LAUNCH (LESS ENGINE) WITH INT-21
SHUTTLE DELIVERY OF OTHER ITEMS

NERVA

THRUST	= 75,000 LB
I_{sp} (NOM)	= 825 SEC
I_{sp} (AVG)	= 775 SEC



SUMMARY WEIGHT - LB		MODE 1	MODE 2
STAGE PLUS RESIDUALS		81,880	85,080
USABLE LPROPELLANT & RCS TRANSLATION		300,132	354,000
OTHER RCS		2,654	2,840
FUEL CELL REACTANTS		1,454	1,500
TOTAL		386,120	443,420
PAYLOAD:	OUTBOUND	175,000	320,000
	RETURN	15,000	16,800

Figure 3.2.2-5 Single Tank RNS

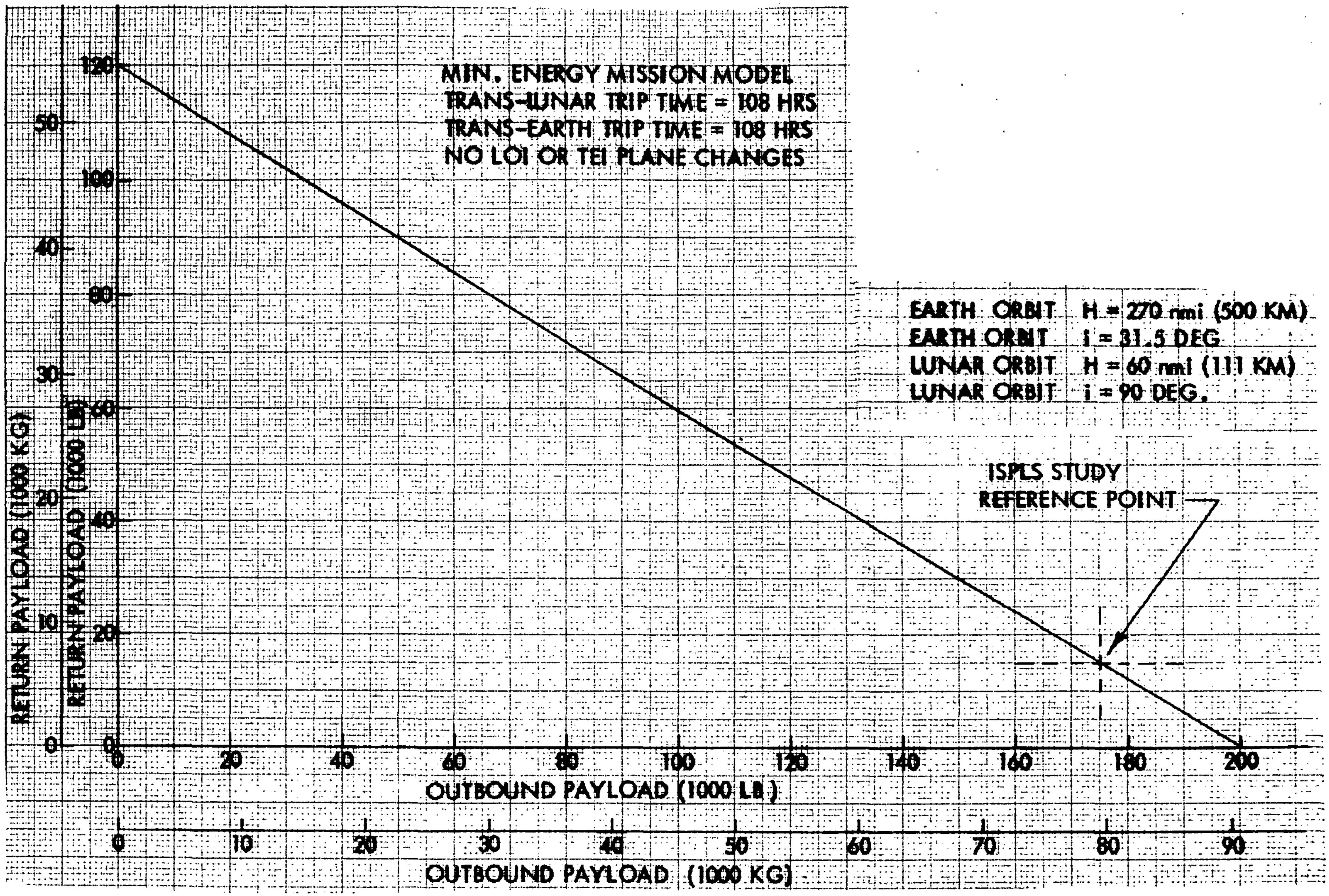
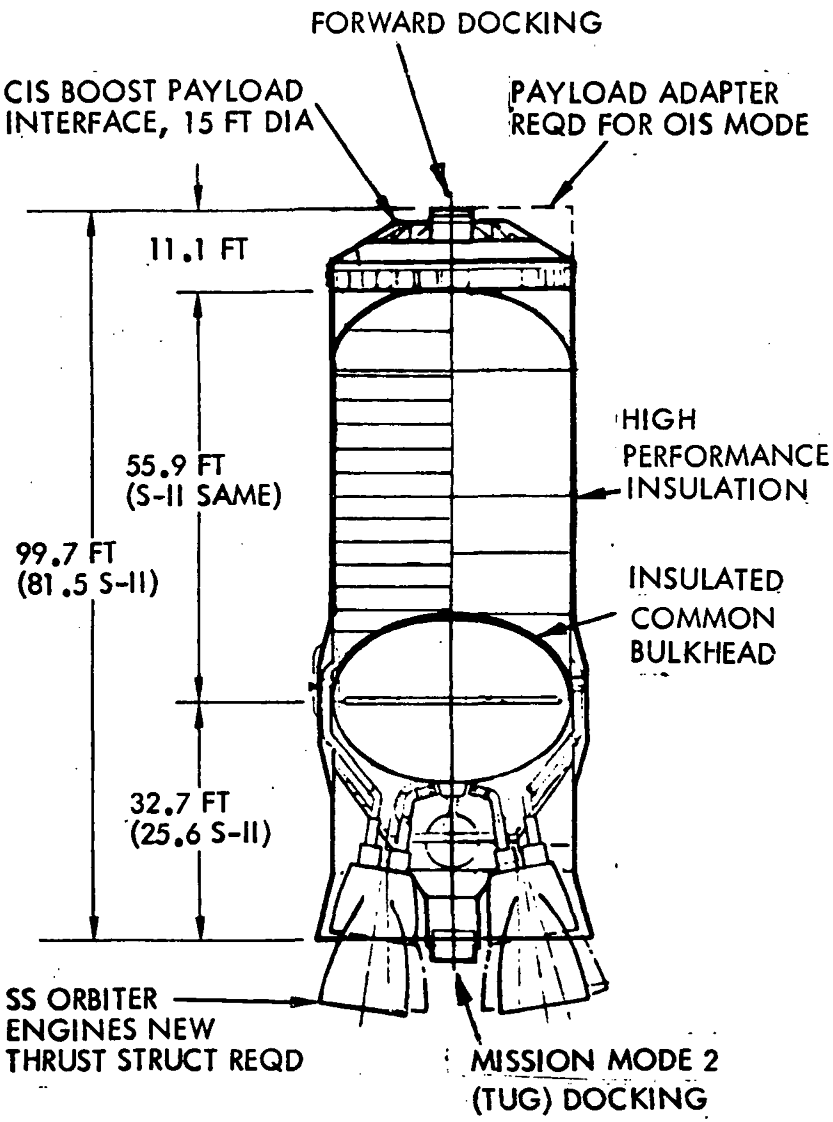


Figure 3.2.2-6 RNS Lunar Shuttle Payload Capability



DESIGN

S-II SIZED TANKS
1974 TECHNOLOGY
3-YEAR OPERATING LIFE OR 10 REUSES
FORWARD & AFT DOCKING

MAIN PROPULSION

2 SHUTTLE ORBITER ENGINES
THRUST: 2 x 632,000 LB
I_{sp} = 460 $\pm$3 SEC @ MR OF 5.5:1

WEIGHTS	MODE 2	MODE 1
BURNOUT	128,626 LB	128,626 LB
PROPELLANTS	1,042,000 *	990,000
INITIAL	1,170,626 LB	1,018,626 LB

LUNAR SHUTTLE PERFORMANCE		
OUTBOUND	320,000 LB	175,000 LB
RETURN	16,800 LB	15,000 LB

*INCLUDES 79000 LBS TUG PROPELLANT

Figure 3.2.2-7 CIS Configuration "A"

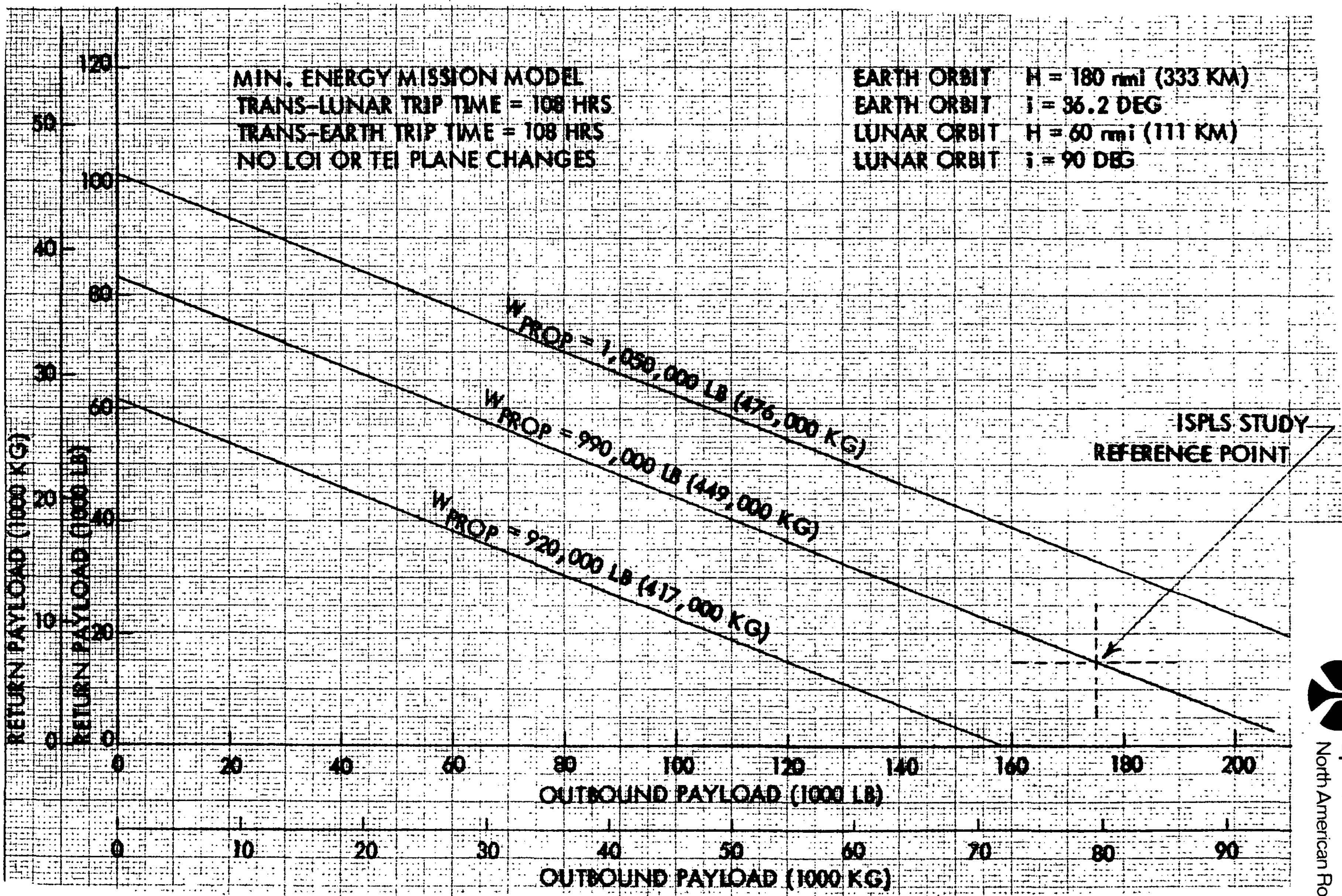
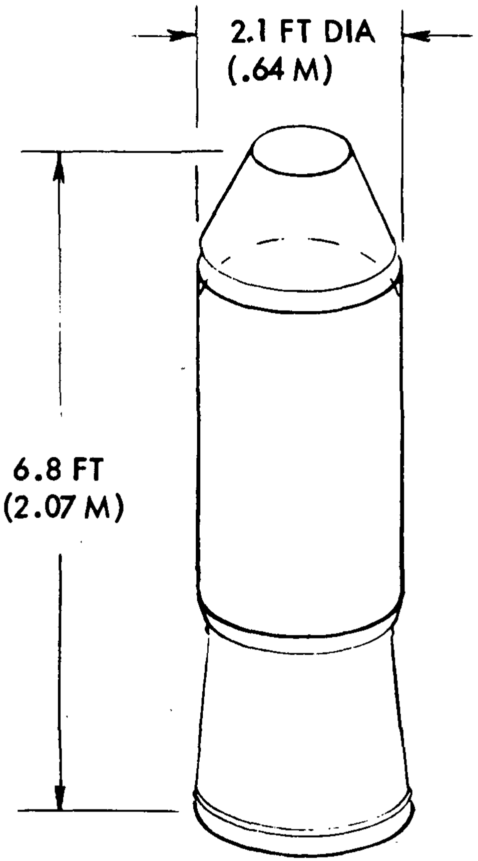


Figure 3.2.2-8 CIS Lunar Shuttle Payload Capability



WEIGHT:	860 LB (390 KG)
PROPELLANT:	SOLID
MADE BY:	UNITED TECHNOLOGY CORP.
STATUS:	OPERATIONAL

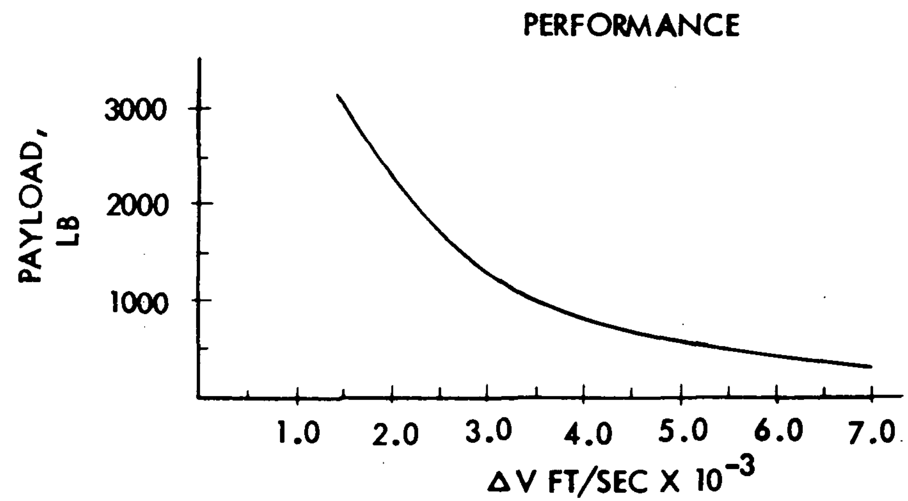
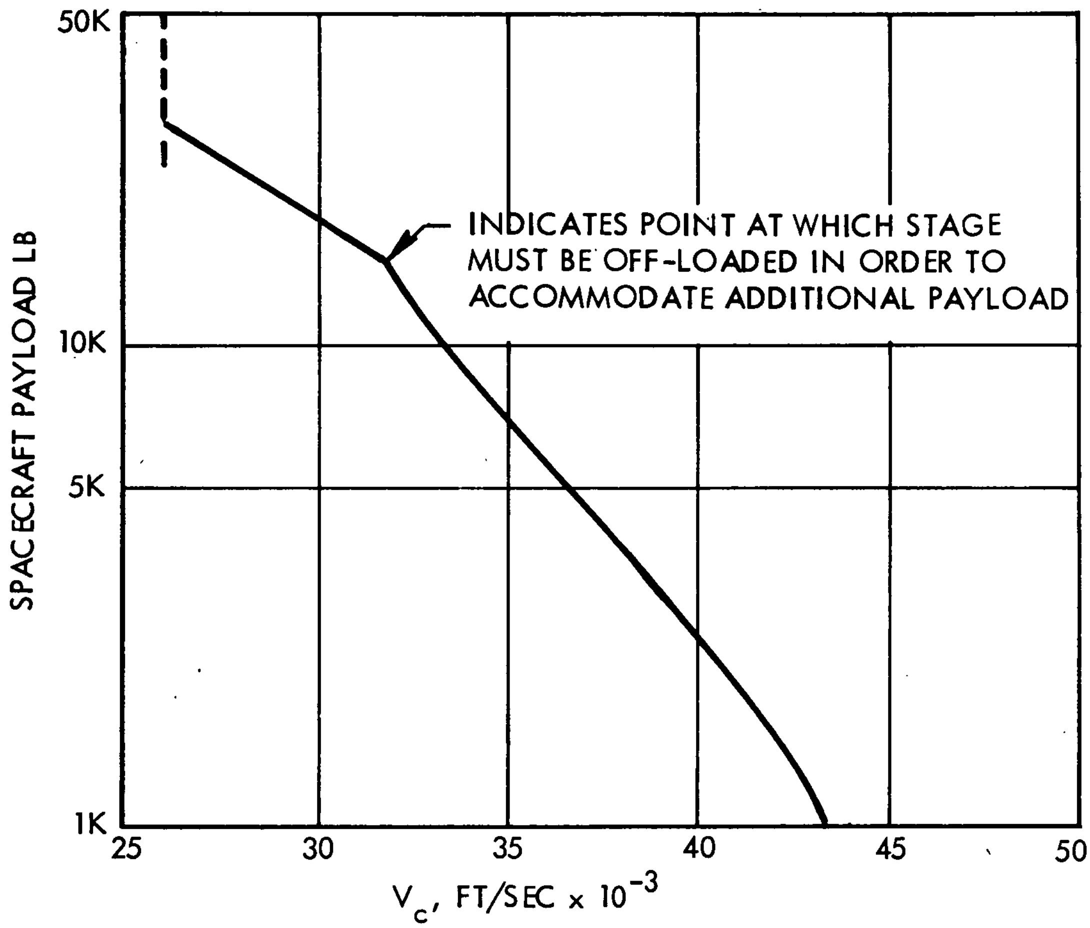


Figure 3.2.2-9 FW-4S Derivative "Kick Stage"



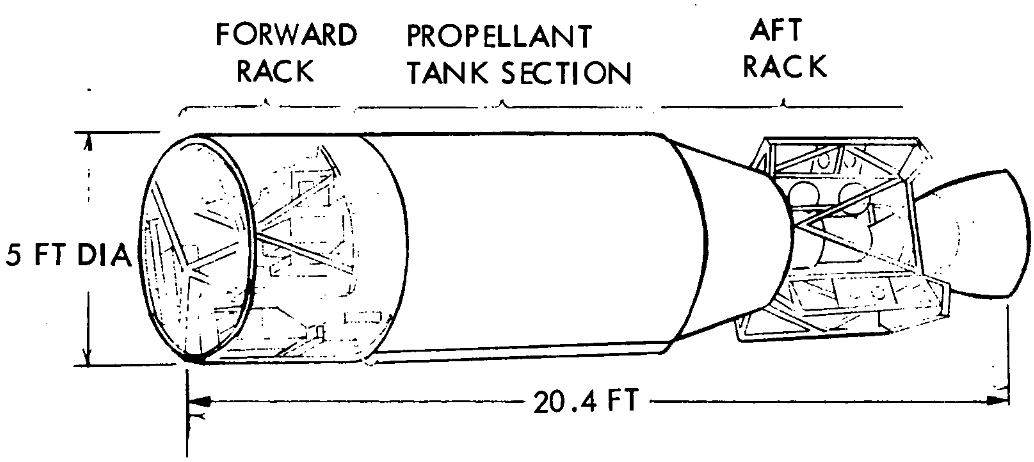


Figure 3.2.2-10 Agena Vehicle

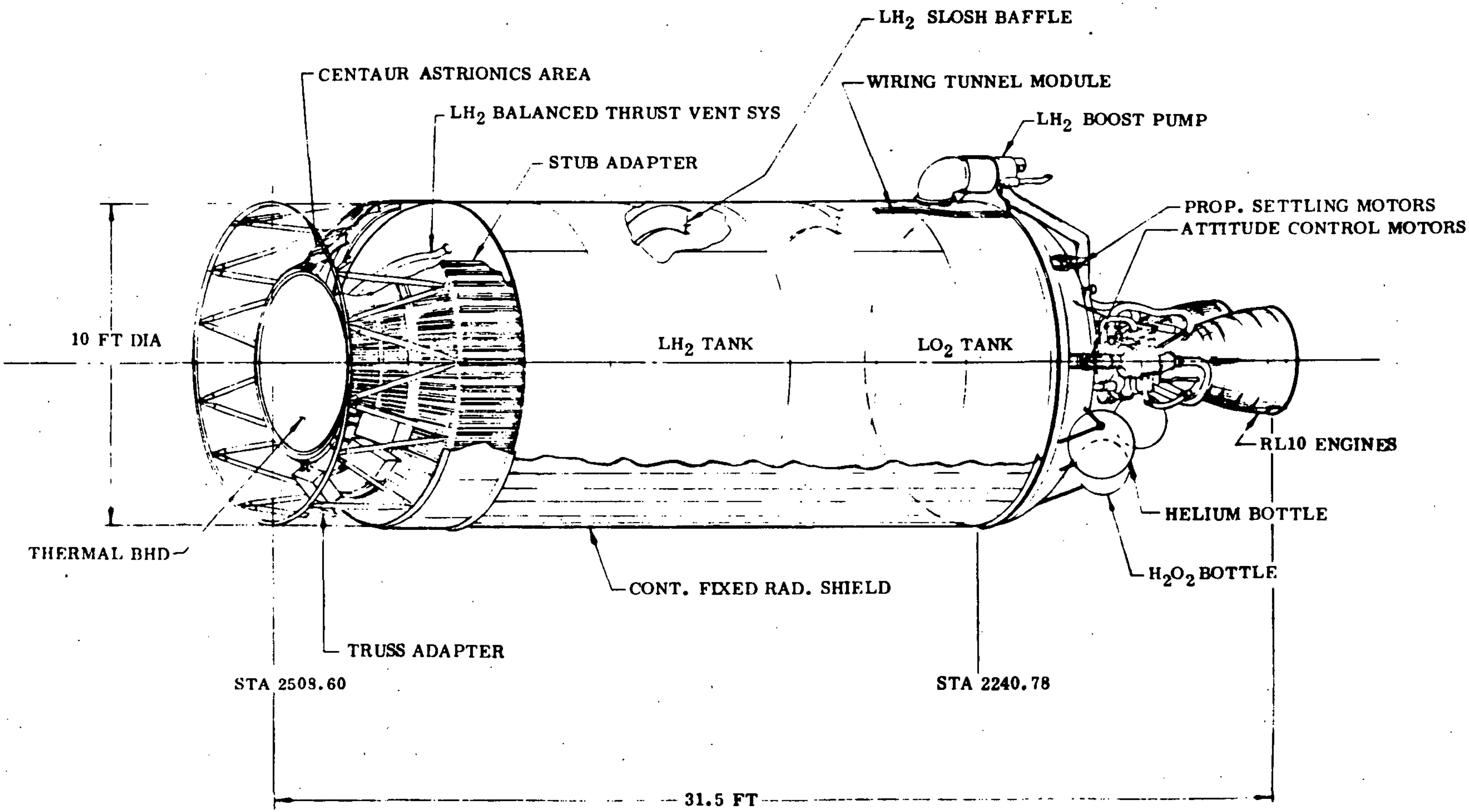


Figure 3.2.2-11 D-IT Centaur Configuration

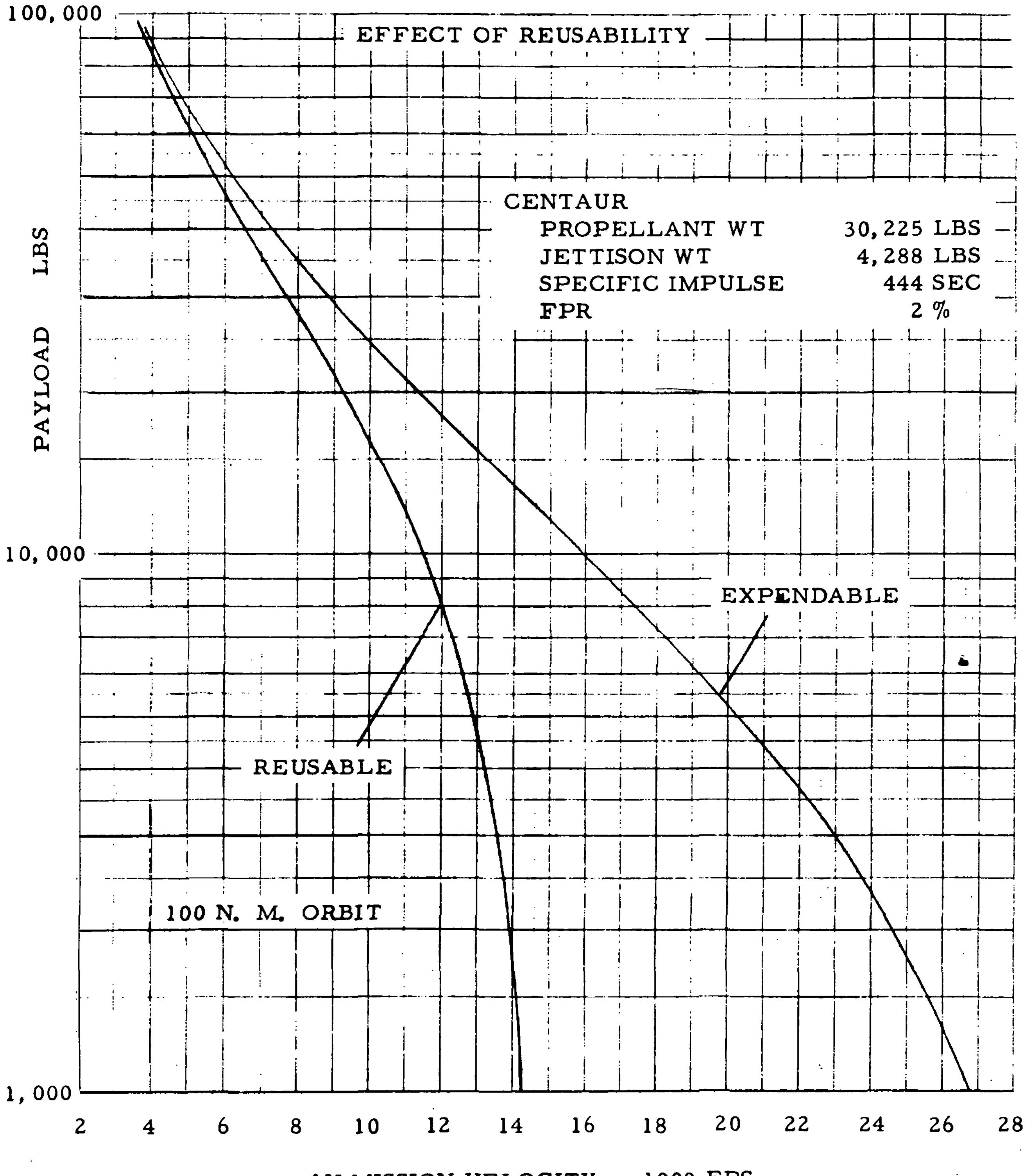


Figure 3.2.2-12 Centaur-STS Performance
Payload Placement

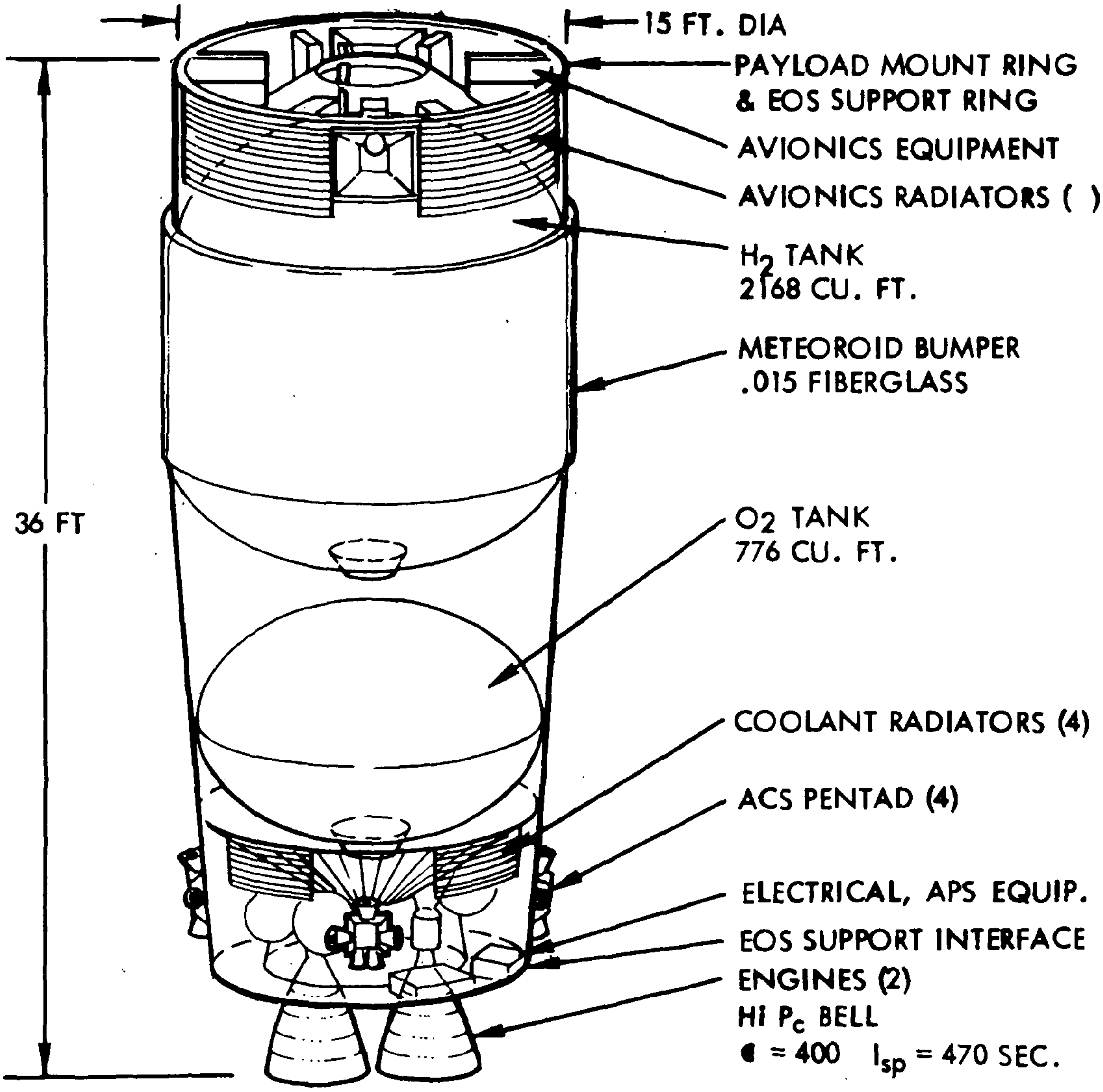


Figure 3.2.2-13 OOS - Single Stage Concept

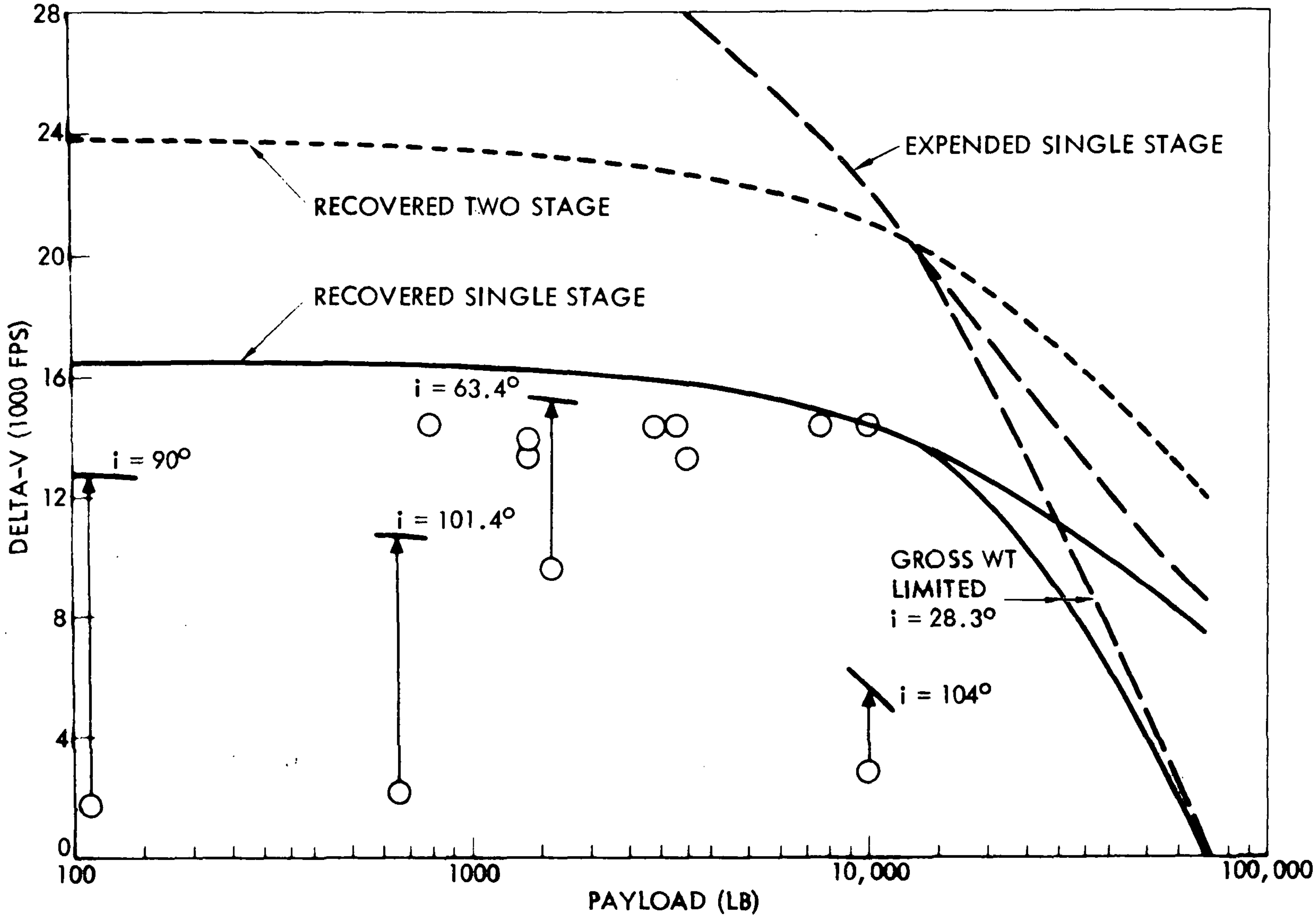


Figure 3.2.2-14 Single Stage Concept Performance - OOS

3.2.3 Vehicle Operational Mode Alternatives

Table 3.2.3-1 presents the vehicles portion of the program composition guide for the alternate space program levels. This complements Table 3.2.1-1 which presents the mission portion. Together, Tables 3.2.1-1 and 3.2.3-1 control the makeup of the parametric space program. (The RNS/CIS major alternatives are not included in Table 3.2.3-1 since they are associated with specific missions and may be considered separately.)

Payload propulsive stage alternatives for use at the alternate program levels represent generally ascending levels of vehicle availability and increasing levels of required program funding. Thus, consistency is maintained with the ascending levels of space mission activity through the A to E levels.

The 12-year program period is split into two 6-year periods in order to accommodate time-phased vehicle IOC dates.

The variables of implementing the programs with different payload propulsive stages are shown by reference to the use of expendables (nonreusable applications of FW-4S, Agena or Centaur derivatives), a ground-based tug (GB tug) or space-based tug (SB tug).

Expendables are shown used for Program Level A exclusively. They are also used for the first six years of Program Levels B, C, D and E in conjunction with either a ground-based tug or space-based tug for the second six-year period.

Program Levels D and E may be implemented with either a ground-based or space-based tug for the full 12-year period. The options shown were selected to provide a broad base for cost comparisons.

3.2.4 Space Traffic Model Descriptions

Each of the five program levels is described by a set of tabular data as shown in Figure 3.2.4-1 through 3.2.4-10. These tabulations are in the same format as the NASA Payload List (Fleming Model) and, as in the summary of Table 3.2.1-1, all missions included in the 12-year program are listed. For each program level, however, only the placements for each mission contained in that program level are included. The 12-year totals for each mission listed in the far right column and the total number of placements in each program level are identical to those shown in the summary of Table 3.2.1-2.

The space traffic model tabulations include the schedule for payload placement missions during the 1979-1990 time period, payload orbit definition, payload size and weight, and the theoretical one-way delta-V requirements for each mission. This information was furnished by NASA as part of the baseline Fleming Model, and was used to select the appropriate payload propulsive stage (nonreusable) for time periods and program levels which do not include a reusable tug as an option. Propulsive stage selection is shown in the applicable column in the tables. This column has been divided into two parts (1979-1984 and 1985-1990) to accommodate the introduction of the reusable tug where appropriate. Payload placement missions which are performed by the

Table 3.2.3-1 Program Level Composition Guide ~ Vehicles

PROGRAM LEVEL (WITH DESIGNATOR)	PAYLOAD PROPULSIVE STAGE	
	1979-1984	1985-1990
A_1	EXPENDABLES	EXPENDABLES
B_1	EXPENDABLES	G. B. TUG
B_2	EXPENDABLES	S. B. TUG
C_1	EXPENDABLES	G. B. TUG
C_2	EXPENDABLES	S. B. TUG
D_1	EXPENDABLES	G. B. TUG
D_2	EXPENDABLES	S. B. TUG
D_3	G. B. TUG	G. B. TUG
D_4	S. B. TUG	S. B. TUG
E_1	EXPENDABLES	G. B. TUG
E_2	EXPENDABLES	S. B. TUG
E_3	G. B. TUG	G. B. TUG
E_4	S. B. TUG	S. B. TUG

MISSION CATEGORY	NO.	MISSION TITLE	ORBIT INCL (°)	ORBIT ALT (nmi)	PAYLOAD DIA X L (FT)	MISSION PAYLOAD LB	ΔV ABOVE 100 X 100 FT/SEC ①	PROPULSIVE STAGE(S) ABOVE SHUTTLE 79-84	PROPULSIVE STAGE(S) ABOVE SHUTTLE 85-90	SCHEDULE OF PLACEMENTS 79	80	81	82	83	84	85	86	87	88	89	90	12-YEAR TOTAL
PHYSICS & ASTRONOMY	1.	ASTRONOMY EXPLORER	28.5	270	1.7 x 2.5	720	592	—— NONE ——		1		1	1	1			1		1	1		7
	2.	RADIO EXPLORER	28.5	19300	4.5 x 3.3	720	13,000	AGENA	AGENA		1				1			1			1	4
	3A.	MAGNETOSPHERE EXPLORER	0	1800 x 180	4 x 8	1,200	11,783	AGENA	AGENA	1								1				2
	3B.	MAGNETOSPHERE EXPLORER	28.5	1800 x 180	4 x 8	1,200	2,510	FW-4S	FW-4S			1								1		2
	3C.	MAGNETOSPHERE EXPLORER	55	1800 x 180	4 x 8	1,200	2,510	FW-4S	FW-4S					1								1
	3D.	MAGNETOSPHERE EXPLORER	90	1800 x 180	4 x 8	1,200	2,510	FW-4S	FW-4S							1						1
	4A.	MAGNETOSPHERE EXPLORER	0	20000 x 1000	5 x 8	1,000	11,158	AGENA	AGENA	1								1				2
	4B.	MAGNETOSPHERE EXPLORER	28.5	20000 x 1000	5 x 8	1,000	10,720	AGENA	AGENA			1								1		2
	4C.	MAGNETOSPHERE EXPLORER	55	20000 x 1000	5 x 8	1,000	10,720	AGENA	AGENA					1								1
	4D.	MAGNETOSPHERE EXPLORER	90	20000 x 1000	5 x 8	1,000	10,720	AGENA	AGENA							1						1
	5A.	MAGNETOSPHERE EXPLORER	0	1 AU	4 x 6	600	13,099	AGENA	AGENA	1								1				2
	5B.	MAGNETOSPHERE EXPLORER	28.5	1 AU	4 x 6	600	11,000	AGENA	AGENA			1								1		2
	5C.	MAGNETOSPHERE EXPLORER	55	1 AU	4 x 6	600	11,000	AGENA	AGENA					1								1
	5D.	MAGNETOSPHERE EXPLORER	90	1 AU	4 x 6	600	11,000	AGENA	AGENA							1						1
	6.	ORBITING SOLAR OBS	30	350	7 x 10	1,900	856	—— NONE ——			1											1
	7A.	GRAVITY/RELATIVITY EXP.	85	300	5 x 7	1,500	692	—— NONE ——													1	1
	7B.	GRAVITY/RELATIVITY EXP.	95	300	5 x 7	1,500	692	—— NONE ——														
	8.	GRAVITY/RELATIVITY EXP	28.5	1 AU	4 x 5	500	11,000	AGENA	AGENA				1									1
	9.	RADIO INTERFEROMETER	28.5	38646	12 x 15	6,000	13,660	CENTAUR	CENTAUR				1									1
	10.	SOLAR ORBIT PAIR	30	19300	10 x 12	1,900	12,917	AGENA	AGENA						1							1
	11.	SOLAR ORBIT PAIR	28.5	1 AU	10 x 12	1,900	11,000	AGENA	AGENA						1							1
	12.	OPTICAL INTERFEROMETER	30	19300	7 x 10	3,500	12,917	CENTAUR	CENTAUR										2			2
	13A.	HEAO	30	230	10 x 34	19,700	468	—— NONE ——			1						1					2
	13B.	HIGH ENERGY STELLAR ASTR.	30	230	14 x 46	21,000	468	—— NONE ——						1							1	2
	14.	HESA REVISITS	30	230	14 x 13	3,500	468	—— NONE ——				1	1	1	2	1	1	1	2	1	1	12
	15A.	LST (STAR)	28.5	350	13 x 45	21,300	856	—— NONE ——						1								1
	15B.	LST (RAM)	28.5	350	14 x 60	30,000	856	—— NONE ——										1				1
	16.	LST (REVISITS)	28.5	350	14 x 13	3,500	856	—— NONE ——							1	1	2	1	1	1	1	8
	17.	LARGE SOLAR OBSERVATORY	30	350	14 x 54	27,000	856	—— NONE ——									1					1
	18.	(LSO REVISITS)	30	350	14 x 13	3,500	856	—— NONE ——										1	1	1	2	5
	19.	LARGE RADIO OBSERVATORY	30	350	14 x 30	19,300	856	—— NONE ——												1		1
	20.	(LRO REVISITS)	30	350	14 x 13	3,500	856	—— NONE ——													2	2
EARTH OBSERVATION	21.	POLAR EARTH OBS. SAT.	99.15	500	6 x 12	2,500	1,330	FW-4S	FW-4S		1		1		1		1		1		1	6
	22.	SYNCH. EARTH OBS. SAT.	0	19300	4 x 6	1,000	14,100	AGENA	AGENA		1				1				1			3
	23.	EARTH PHYSICS SAT.	90	400	3.5 x 6.5	600	1,020	FW-4S	FW-4S		1			1			1					3
	24.	SYNCH. METEOROLOGICAL SAT.	0	19300	5 x 8	1,000	14,100	AGENA	AGENA				1									1
	25.	TIROS	100.7	700	5 x 10	1,000	1,940	FW-4S	FW-4S			1				1						2
	26.	POLAR EARTH RESOURCES SAT.	99.15	500	6 x 12	2,500	1,330	FW-4S	FW-4S								1	2				3
	27.	SYNCH. EARTH RESOURCES SAT.	0	19300	4 x 6	1,000	14,100	AGENA	AGENA				1	1				1	1			4
COMMUNI-CATION/ NAVIGATION	28.	APPLICATIONS TECH. SAT.	0	19300	15 x 20	7,950	14,100	CENTAUR	CENTAUR	1				1			1			1		4
	29.	SMALL APPLICATIONS SAT.	0	19300	6.5 x 12	600	14,100	AGENA	AGENA		1		1		1		1		1		1	6
	30.	SMALL APPLICATIONS SAT.	90	3000 x 300	6.5 x 12	600	3,800	FW-4S	FW-4S		1		1		1		1		1		1	6
	31.	COOPERATIVE APPLICATIONS	0	19300	6.5 x 12	820	14,100	AGENA	AGENA	1					1							2
	32.	COOPERATIVE APPLICATIONS	90	3000 x 300	6.5 x 12	820	3,800	FW-4S	FW-4S				1							1		2
	33.	MEDICAL NETWORK SAT.	0	19300	12 x 15	2,000	14,100	AGENA	AGENA	2												2
	34.	EDUCATION BROADCAST SAT.	0	19300	10 x 19	2,145	14,100	AGENA	AGENA			2										2
	35.	FOLLOW-ON SYSTEM DEMO.	0	19300	12 x 15	2,000	14,100	AGENA	AGENA					1		1		1	1	1	1	6
	36.	TRACKING & DATA RELAY	0	19300	12 x 15	2,300	14,100	AGENA	AGENA		1	1				1	1				1	5
	37.	PLANETARY RELAY SAT. (DELETED)	0	19300	10 x 20	1,000	14,100	——	——													0

① THEORETICAL MINIMUM, ONE-WAY, POINT-TO-POINT ΔV

REVISED 22 NOV '71

Figure 3.2.4-1 Program Level A Space Traffic Model Data (Part 1)

SD72-SA-0053-2

Space Division North American Rockwell

MISSION CATEGORY	NO.	MISSION TITLE	ORBIT INCL. (°)	ORBIT ALT (nmi)	PAYLOAD DIA X L (FT)	MISSION PAYLOAD LB	ΔV ABOVE 100 X 100 FT/SEC ①	PROPULSIVE STAGE(S) ABOVE SHUTTLE 79-84	PROPULSIVE STAGE(S) ABOVE SHUTTLE 85-90	79	80	81	82	83	84	85	86	87	88	89	90	12-YEAR TOTAL
SORTIES	38.	GEN. SCIENCE RES. MODULE	55	200	14 x 54	27,500	360	— NONE —				1	1	2	2	1						7
	39.	GEN. APPL. MODULE	65	100	14 x 51	30,000	0	— NONE —				1	2	1	1	1	1		1	1		9
	40.	DED. SCI. & RES. MOD. ASTR.	55	200	14 x 54	29,500	360	— NONE —							1	1	2	2	2	3	2	13
	41.	DED. APPL. MOD. - EARTH OBS. PALLET TYPE MODULE	75	100	14 x 51	22,500	0	— NONE —							1	1	1	1	1	1	2	8
	42.	EARTH OBSERVATION	90	125	14 x 37	6,000	171	— NONE —			1		1									2
	43.	BIOLOGICAL RESEARCH	28.5	200	14 x 37	4,300	360	— NONE —		1												1
	44.	ASTRONOMY	28.5	200	14 x 37	5,700	360	— NONE —			1	1	1	1								4
	45.	FLUID MANAGEMENT	28.5	200	14 x 37	7,100	360	— NONE —			1											1
	46.	TELEOPERATOR	28.5	200	14 x 37	5,000	360	— NONE —			1											1
	47.	MANNED WORK PLATFORM	28.5	200	14 x 37	6,700	360	— NONE —				1										1
	48.	LARGE TELESCOPE MIRROR TEST	28.5	200	14 x 37	13,000	360	— NONE —		1												1
	49.	ASTRONAUT MAN. UNIT (AMU)	28.5	200	14 x 37	3,800	360	— NONE —			1											1
PLANETARY	50	VIKING	30	1.52 AU	10 x 12	7,700	15,400	CENTAUR		1		1										2
	51	MARS SAMPLE RETURN	30	1.52 AU	14 x 22.5	22,000	15,400	—	2 CENTAURS ②												2	2
	52	VENUS EXPLORER	30	.723 AU	5 x 12	1,000	13,400	AGENA	AGENA		1											1
	53	VENUS RADAR MAPPING	30	.723 AU	10 x 12	7,900	13,400	CENTAUR	CENTAUR				1									1
	54	VENUS EXPLORER LANDER	30	.723 AU	10 x 15	7,300	13,400	CENTAUR	CENTAUR							1			1			2
	55	JUPITER PIONEER ORBITER	30	5.20 AU	10 x 15	900	22,700	CENTAUR	CENTAUR				2									2
	56	GRAND TOUR (JUN)	30	30.06 AU	10 x 12	1,500	25,900	2 CENTAURS ②	2 CENTAURS ②	2												2
	57	JUPITER TOPS ORBITER/PROBE	30	5.20 AU	10 x 15	3,300	22,700	2 CENTAURS ②	2 CENTAURS ②							1		1				2
	58	URANUS TOPS ORBITER/PROBE	30	19.18 AU	10 x 15	3,700	24,000	2 CENTAURS ②	2 CENTAURS ②								1			1		2
	59	ASTEROID SURVEY	30	2.9 AU	10 x 35	27,000	13,400	2 CENTAURS ②	2 CENTAURS ②						1							1
	60	COMET RENDEZVOUS	30	.34 AU	10 x 35	24,000	13,400	2 CENTAURS ②	2 CENTAURS ②				1			1						2
	60-3	SATURN ORBITER	30	9.54 AU	12 X 22.5	4,050	25,500 ③	—	—													0
	P-2	VENUS SURFACE SAMPLE & RETURN	30	.723 AU	15 X 170 ②	185,000	13,115 ③	—	—													0
	P-3	MARS SURFACE SAMPLE & RETURN	30	1.52 AU	15 X 124 ②	134,000	15,115 ③	—	—													0
	P-4	JUP ORB./PROBES & SAT. LANDERS	30	5.20 AU	15 X 65 ②	70,000	22,415 ③	—	—													0
SPACE STATION	61	STATION MODULES - CORE	55	270	14 x 40	20,000	592	— NONE —														0
	62	STATION MODULES - OTHERS	55	270	14 x 30	20,000	592	— NONE —														0
	63	CREW CARGO	55	270	14 x 30	20,000	592	— NONE —														0
	64	PHYSICS LAB	55	270	14 x 32	22,000	592	— NONE —														0
	65	COSMIC RAY LAB	55	270	14 x 52	30,000	592	— NONE —														0
	66	LIFE SCIENCE LAB	55	270	14 x 58	33,000	592	— NONE —														0
	67	EARTH OBSERVATIONS LAB	55	270	14 x 45	25,000	592	— NONE —														0
	68	COMM/NAVIGATION LAB	55	270	14 x 38	19,000	592	— NONE —														0
	69	SPACE MANUFACTURING LAB	55	270	14 x 45	25,000	592	— NONE —														0
NON-NASA	70	COMSAT SATELLITES	0	19,300	6.5 x 12	1,420	14,100	AGENA	AGENA		1	1			1	1			1	1		6
	71	U.S. DOMESTIC COMM	0	19,300	10 x 19	2,145	14,100	AGENA	AGENA		1	1		1	1	1	1	1	1	1	1	10
	72	FOREIGN DOMESTIC COMM.	28.5	19,300	4 x 12	1,000	13,000	AGENA	AGENA	1	1	1	1	1	1	1	1	1	1	1	2	13
	73	NAV & TRAFFIC CONTROL	29	30000 x 16000	5 x 8	700	13,948	AGENA	AGENA	1		1			1		1			1		5
	74	NAV & TRAFFIC CONTROL	5	19,300	5 x 8	700	13,400	AGENA	AGENA			1				1				1		3
	75	TOS METEOROLOGICAL	100.7	700	5 x 6	1,000	1,940	FW-4S	FW-4S	1		1		1		1		1		1		6
	76	SYNC METEOROLOGICAL	0	19,300	5 x 8	1,000	14,100	AGENA	AGENA		1		1		1		1		1		1	6
	77	POLAR EARTH RESOURCES	99.15	500	12 x 15	2,500	1,330	FW-4S	FW-4S	2		2		2			2			3		11
	78	SYNCH EARTH RESOURCES	0	19,300	6 x 6	1,000	14,100	AGENA	AGENA							2			2			4
	78-2	COMM SATS IN GENERAL	0	19,300	8 X 10	850	14,100	—	—													0
	78-3	BROADCAST SAT INDIVIDUAL RECEP	0	19,300	10 X 12.5	2,500	14,100	—	—													0
	78-4	BROADCAST SAT COMMUNITY RECEP	0	19,300	8 X 10	1,000	14,100	—	—													0
LUNAR	L-1	AUTO. LUNAR PROG. ORBITERS	28.5	100	15 X 31	1,600	10,400	—	—													0
	L-2	AUTO. LUNAR PROG. LANDERS	28.5	100	15 X 31	16,500	10,400	—	—													0
	L-3	MANNED SORTIE-CLASS MISS.	31.5	260	15 X 162 ②			—	—													0
	L-4	POST-SORTIE SURF. OPERATIONS	31.5	260	15 X 162 ②			—	—													0
TOTAL										18	19	22	21	20	22	22	24	19	24	26	24	261

① THEORETICAL MINIMUM, ONE-WAY, POINT-TO-POINT ΔV.
② ASSEMBLED IN SPACE
③ ΔV ABOVE 180 X 180 nmi

Figure 3.2.4-2 Program Level A Space Traffic Model Data (Part 2)

REVISED 22 NOV '71

MISSION CATEGORY	NO.	MISSION TITLE	ORBIT INCL (°)	ORBIT ALT (nmi)	PAYLOAD DIA X L (FT)	MISSION PAYLOAD LB	ΔV ABOVE 100 X 100 FT/SEC ①	PROPULSIVE STAGE(S) ABOVE SHUTTLE 79-84	PROPULSIVE STAGE(S) ABOVE SHUTTLE 85-90	79	80	81	82	83	84	85	86	87	88	89	90	12-YEAR TOTAL
PHYSICS & ASTRONOMY	1.	ASTRONOMY EXPLORER	28.5	270	1.7 x 2.5	720	592	NONE	NONE	1		1	1	2	1		1	1	1	2		11
	2.	RADIO EXPLORER	28.5	19300	4.5 x 3.3	720	13,000	AGENA	TUG		1	1			1	1		1			1	6
	3A.	MAGNETOSPHERE EXPLORER	0	1800 x 180	4 x 8	1,200	11,783	AGENA	TUG	1					1						1	3
	3B.	MAGNETOSPHERE EXPLORER	28.5	1800 x 180	4 x 8	1,200	2,510	FW-4S	TUG		1						1					2
	3C.	MAGNETOSPHERE EXPLORER	55	1800 x 180	4 x 8	1,200	2,510	FW-4S	TUG				1					1				2
	3D.	MAGNETOSPHERE EXPLORER	90	1800 x 180	4 x 8	1,200	2,510	FW-4S	TUG					1					1			2
	4A.	MAGNETOSPHERE EXPLORER	0	20000 x 1000	5 x 8	1,000	11,158	AGENA	TUG	1					1						1	3
	4B.	MAGNETOSPHERE EXPLORER	28.5	20000 x 1000	5 x 8	1,000	10,720	AGENA	TUG		1						1					2
	4C.	MAGNETOSPHERE EXPLORER	55	20000 x 1000	5 x 8	1,000	10,720	AGENA	TUG				1					1				2
	4D.	MAGNETOSPHERE EXPLORER	90	20000 x 1000	5 x 8	1,000	10,720	AGENA	TUG					1					1			2
	5A.	MAGNETOSPHERE EXPLORER	0	1 AU	4 x 6	600	13,099	AGENA	TUG	1					1						1	3
	5B.	MAGNETOSPHERE EXPLORER	28.5	1 AU	4 x 6	600	11,000	AGENA	TUG		1						1					2
	5C.	MAGNETOSPHERE EXPLORER	55	1 AU	4 x 6	600	11,000	AGENA	TUG				1					1				2
	5D.	MAGNETOSPHERE EXPLORER	90	1 AU	4 x 6	600	11,000	AGENA	TUG					1					1			2
	6.	ORBITING SOLAR OBS	30	350	7 x 10	1,900	856	NONE	NONE		1											1
	7A.	GRAVITY/RELATIVITY EXP.	85	300	5 x 7	1,500	692	NONE	NONE						1							1
	7B.	GRAVITY/RELATIVITY EXP.	95	300	5 x 7	1,500	692	NONE	NONE												1	1
	8.	GRAVITY/RELATIVITY EXP	28.5	1AU	4 x 5	500	11,000	AGENA	TUG			1						1				2
	9.	RADIO INTERFEROMETER	28.5	38646	12 x 15	6,000	13,660	CENTAUR				1										1
	10.	SOLAR ORBIT PAIR	30	19300	10 x 12	1,900	12,917	AGENA	TUG						1					1		2
	11.	SOLAR ORBIT PAIR	28.5	1AU	10 x 12	1,900	11,000	AGENA	TUG						1					1		2
	12.	OPTICAL INTERFEROMETER	30	19300	7 x 10	3,500	12,917	CENTAUR	TUG										2			2
	13A.	HEAO	30	230	10 x 34	19,700	468	NONE	NONE		1						1					2
	13B.	HIGH ENERGY STELLAR ASTR.	30	230	14 x 46	21,000	468	NONE	NONE					1							1	2
	14.	HESA REVISITS	30	230	14 x 13	3,500	468	NONE	NONE			2	2	1	2	2	1	2	1	2	1	16
	15A.	LST (STAR)	28.5	350	13 x 45	21,300	856	NONE	NONE					1								1
	15B.	LST (RAM)	28.5	350	14 x 60	30,000	856	NONE	NONE									1				1
	16.	LST (REVISITS)	28.5	350	14 x 13	3,500	856	NONE	NONE						2	2	2	1	2	2	1	12
	17.	LARGE SOLAR OBSERVATORY	30	350	14 x 54	27,000	856	NONE	NONE							1					1	2
	18.	(LSO REVISITS)	30	350	14 x 13	3,500	856	NONE	NONE								2	2	2	2	1	9
	19.	LARGE RADIO OBSERVATORY	30	350	14 x 30	19,300	856	NONE	NONE									1				1
	20.	(LRO REVISITS)	30	350	14 x 13	3,500	856	NONE	NONE										2	2	2	6
EARTH OBSERVATION	21.	POLAR EARTH OBS. SAT.	99.15	500	6 x 12	2,500	1,330	FW-4S	TUG	1	1	1		1	1	1		1	1	1		9
	22.	SYNCH. EARTH OBS. SAT.	0	19300	4 x 6	1,000	14,100	AGENA	TUG		1			1			1			1		4
	23.	EARTH PHYSICS SAT.	90	400	3.5 x 6.5	600	1,020	FW-4S	TUG		1		1			1		1		1		5
	24.	SYNCH. METEOROLOGICAL SAT.	0	19300	5 x 8	1,000	14,100	AGENA	—				1	1								2
	25.	TIROS	100.7	700	5 x 10	1,000	1,940	FW-4S	TUG			1				1						2
	26.	POLAR EARTH RESOURCES SAT.	99.15	500	6 x 12	2,500	1,330	—	TUG								2	3				5
	27.	SYNCH. EARTH RESOURCES SAT.	0	19300	4 x 6	1,000	14,100	AGENA	TUG			1	1	1				1	1			5
COMMUNI-CATION/ NAVIGATION	28.	APPLICATIONS TECH. SAT.	0	19300	15 x 20	7,950	14,100	CENTAUR	2 TUGS ②	1		1		1			1			1		5
	29.	SMALL APPLICATIONS SAT.	0	19300	6.5 x 12	600	14,100	AGENA	TUG	1	1		1	1	1		1	1	1		1	9
	30.	SMALL APPLICATIONS SAT.	90	3000 x 300	6.5 x 12	600	3,800	FW-4S	TUG	1	1		1	1	1		1	1	1		1	9
	31.	COOPERATIVE APPLICATIONS	0	19300	6.5 x 12	820	14,100	AGENA	—	1					1							2
	32.	COOPERATIVE APPLICATIONS	90	3000 x 300	6.5 x 12	820	3,800	FW-4S	TUG				1							1		2
	33.	MEDICAL NETWORK SAT.	0	19300	12 x 15	2,000	14,100	AGENA	—	2												2
	34.	EDUCATION BROADCAST SAT.	0	19300	10 x 19	2,145	14,100	AGENA	—		2											2
	35.	FOLLOW-ON SYSTEM DEMO.	0	19300	12 x 15	2,000	14,100	AGENA	TUG			2	1	1	1	2	1	1	1	2	1	13
	36.	TRACKING & DATA RELAY	0	19300	12 x 15	2,300	14,100	AGENA	TUG	1	1	1		1	1			1	1			7
	37.	PLANETARY RELAY SAT.	0	19300	10 x 20	1,000	14,100	—	—													0

① THEORETICAL MINIMUM, ONE-WAY, POINT-TO-POINT ΔV
② ASSEMBLED IN SPACE

REVISED 22 NOV '71

Figure 3.2.4-3 Program Level B Space Traffic Model Data
(Part I)

Space Division
North American Rockwell

MISSION CATEGORY	NO.	MISSION TITLE	ORBIT INCL (°)	ORBIT ALT (nmi)	PAYLOAD DIA X L (FT)	MISSION PAYLOAD LB	ΔV ABOVE 100 X 100 FT/SEC ①	PROPULSIVE STAGE(S) ABOVE SHUTTLE 79-84	PROPULSIVE STAGE(S) ABOVE SHUTTLE 85-90	79	80	81	82	83	84	85	86	87	88	89	90	12-YEAR TOTAL
SORTIES	38.	GEN. SCIENCE RES. MODULE	55	200	14 x 54	27,500	360	NONE	NONE			2	2	3	3	2						12
	39.	GEN. APPL. MODULE	65	100	14 x 51	30,000	0	NONE	NONE			1	2	2	2	2	2		2	1		14
	40.	DED. SCI. & RES. MOD. ASTR.	55	200	14 x 54	29,500	360	NONE	NONE						1	2	3	4	3	4	3	20
	41.	DED. APPL. MOD. - EARTH OBS. PALLET TYPE MODULE	75	100	14 x 51	22,500	0	NONE	NONE						1	2	1	2	1	2	3	12
	42.	EARTH OBSERVATION	90	125	14 x 37	6,000	171	NONE	NONE		1	1	1									3
	43.	BIOLOGICAL RESEARCH	28.5	200	14 x 37	4,300	360	NONE	NONE	1												1
	44.	ASTRONOMY	28.5	200	14 x 37	5,700	360	NONE	NONE		1	2	1	1								5
	45.	FLUID MANAGEMENT	28.5	200	14 x 37	7,100	360	NONE	NONE		1			1								2
	46.	TELEOPERATOR	28.5	200	14 x 37	5,000	360	NONE	NONE		1											1
	47.	MANNED WORK PLATFORM	28.5	200	14 x 37	6,700	360	NONE	NONE			1										1
	48.	LARGE TELESCOPE MIRROR TEST	28.5	200	14 x 37	13,000	360	NONE	NONE	1												1
	49.	ASTRONAUT MAN. UNIT (AMU)	28.5	200	14 x 37	3,800	360	NONE	NONE		1											1
PLANETARY	50	VIKING	30	1.52 AU	10 x 12	7,700	15,400	CENTAUR	—	1		1										2
	51	MARS SAMPLE RETURN	30	1.52 AU	14 x 22.5	22,000	15,400	—	2 TUGS ②												2	2
	52	VENUS EXPLORER	30	.723 AU	5 x 12	1,000	13,400	AGENA	—		1											1
	53	VENUS RADAR MAPPING	30	.723 AU	10 x 12	7,900	13,400	CENTAUR	—				1									1
	54	VENUS EXPLORER LANDER	30	.723 AU	10 x 15	7,300	13,400	—	TUG							1			1			2
	55	JUPITER PIONEER ORBITER	30	5.20 AU	10 x 15	900	22,700	CENTAUR	—				2									2
	56	GRAND TOUR (JUN)	30	30.06 AU	10 x 12	1,500	25,900	2 CENTAURS ②	—	2												2
	57	JUPITER TOPS ORBITER/PROBE	30	5.20 AU	10 x 15	3,300	22,700	—	TUG							1		1				2
	58	URANUS TOPS ORBITER/PROBE	30	19.18 AU	10 x 15	3,700	24,000	—	TUG								1			1		2
	59	ASTEROID SURVEY	30	2.9 AU	10 x 35	27,000	13,400	2 CENTAURS ②	—						1							1
	60	COMET RENDEZVOUS	30	.34 AU	10 x 35	24,000	13,400 ③	2 CENTAURS ②	2 TUGS ②				1			1						2
	60-3	SATURN ORBITER	30	9.54 AU	12 X 22.5	4,050	25,500 ③	—	—													0
	P-2	VENUS SURF. SAMPLE & RET.	30	.723 AU	15 X 170 ②	185,000	13,115 ③	—	—													0
	P-3	MARS SURF. SAMPLE & RET.	30	1.52 AU	15 X 124 ②	134,000	15,115 ③	—	—													0
	P-4	JUP ORB./PROBES & SAT. LANDERS	30	5.20 AU	15 X 65 ②	70,000	22,415 ③	—	—													0
SPACE STATION	61	STATION MODULES-CORE	55	270	14 x 40	20,000	592	NONE	NONE				1			1	1	3	2			8
	62	STATION MODULES - OTHERS	55	270	14 x 30	20,000	592	NONE	NONE				5				3					8
	63	CREW CARGO	55	270	14 x 30	20,000	592	NONE	NONE				1	6	6	6	6	8	8	8	8	57
	64	PHYSICS LAB	55	270	14 x 32	22,000	592	NONE	NONE						1							1
	65	COSMIC RAY LAB	55	270	14 x 52	30,000	592	NONE	NONE											1		1
	66	LIFE SCIENCE LAB	55	270	14 x 58	33,000	592	NONE	NONE				1				1					2
	67	EARTH OBSERVATIONS LAB	55	270	14 x 45	25,000	592	NONE	NONE				1				1					2
	68	COMM/NAVIGATION LAB	55	270	14 x 38	19,000	592	NONE	NONE					1								1
	69	SPACE MANUFACTURING LAB	55	270	14 x 45	25,000	592	NONE	NONE													0
NON-NASA	70	COMSAT SATELLITES	0	19300	6.5 x 12	1,420	14,100	AGENA	TUG	1	1	1		1	1	1			1	1		8
	71	U.S. DOMESTIC COMM	0	19300	10 x 19	2,145	14,100	AGENA	TUG	1	1	1	1	1	1	1	2	1	2	2	2	16
	72	FOREIGN DOMESTIC COMM.	28.5	19300	4 x 12	1,000	13,000	AGENA	TUG		1	4	2	2			3	3	1	1	2	19
	73	NAV & TRAFFIC CONTROL	29	30000 x 16000	5 x 8	700	13,948	AGENA	TUG	2	1	1		1		1		1		1		8
	74	NAV & TRAFFIC CONTROL	5	19300	5 x 8	700	13,400	AGENA	TUG		1	1			1			1			1	5
	75	TOS METEOROLOGICAL	100.7	700	5 x 6	1,000	1,940	FW-4S	TUG	1	1	1		1	1		1	1	1		1	9
	76	SYNC METEOROLOGICAL	0	19300	5 x 8	1,000	14,100	AGENA	TUG	1	1	1		1	1		1	1	1		1	9
	77	POLAR EARTH RESOURCES	99.15	500	12 x 15	2,500	1,330	FW-4S	TUG	4			4			4				4		16
	78	SYNCH EARTH RESOURCES	0	19300	6 x 6	1,000	14,100	—	TUG							3			3			6
	78-2	COMM. SATS. IN GENERAL	14,100	850	8 X 10	850	14,100	—	—													0
	78-3	BROADCAST SAT. IND. RECEP.	14,100	2,500	10 X 12.5	2,500	14,100	—	—													0
	78-4	BROADCAST SAT. COMM. RECEP.	14,100	1,000	8 X 10	1,000	14,100	—	—													0
LUNAR	L-1	AUTO. LUNAR PROG. ORBITERS	28.5	100	15 X 31	1,600	10,400	—	—													0
	L-2	AUTO. LUNAR PROG. LANDERS	28.5	100	15 X 31	16,500	10,400	—	—													0
	L-3	MANNED SORTIE-CLASS MISS.	31.5	260	15 X 162 ②			—	—													0
	L-4	POST-SORTIE SURF. OPERATIONS	31.5	260	15 X 162 ②			—	—													0
TOTAL										27	27	31	39	38	38	39	43	49	45	45	38	459

① THEORETICAL MINIMUM, ONE-WAY, POINT-TO-POINT ΔV
② ASSEMBLED IN SPACE
③ ΔV ABOVE 180 x 180 nmi

REVISED 22 NOV '71

Figure 3.2.4-4 Program Level B Space Traffic Model Data (Part 2)

Space Division
North American Rockwell

MISSION CATEGORY	NO.	MISSION TITLE	ORBIT INCL (°)	ORBIT ALT (nmi)	PAYLOAD DIA X L (FT)	MISSION PAYLOAD LB	ΔV ABOVE 100 X 100 FT/SEC ①	PROPULSIVE STAGE(S) ABOVE SHUTTLE 79-84	PROPULSIVE STAGE(S) ABOVE SHUTTLE 85-90	79	80	81	82	83	84	85	86	87	88	89	90	12-YEAR TOTAL
PHYSICS & ASTRONOMY	1.	ASTRONOMY EXPLORER	28.5	270	1.7 x 2.5	720	592	——— NONE ———		2		1	2	2	1		2	1	2	2		15
	2.	RADIO EXPLORER	28.5	19300	4.5 x 3.3	720	13,000	AGENA	TUG		2	1			1	2		1			2	9
	3A.	MAGNETOSPHERE EXPLORER	0	1800 x 180	4 x 8	1,200	11,783	AGENA	TUG	1				1				1				3
	3B.	MAGNETOSPHERE EXPLORER	28.5	1800 x 180	4 x 8	1,200	2,510	FW-4S	TUG		1				1				1			3
	3C.	MAGNETOSPHERE EXPLORER	55	1800 x 180	4 x 8	1,200	2,510	FW-4S	TUG			1				1				1		3
	3D.	MAGNETOSPHERE EXPLORER	90	1800 x 180	4 x 8	1,200	2,510	FW-4S	TUG				1				1				1	3
	4A.	MAGNETOSPHERE EXPLORER	0	20000 x 1000	5 x 8	1,000	11,158	AGENA	TUG	1				1				1				3
	4B.	MAGNETOSPHERE EXPLORER	28.5	20000 x 1000	5 x 8	1,000	10,720	AGENA	TUG		1				1				1			3
	4C.	MAGNETOSPHERE EXPLORER	55	20000 x 1000	5 x 8	1,000	10,720	AGENA	TUG			1				1				1		3
	4D.	MAGNETOSPHERE EXPLORER	90	20000 x 1000	5 x 8	1,000	10,720	AGENA	TUG				1				1				1	3
	5A.	MAGNETOSPHERE EXPLORER	0	1 AU	4 x 6	600	13,099	AGENA	TUG	1				1				1				3
	5B.	MAGNETOSPHERE EXPLORER	28.5	1 AU	4 x 6	600	11,000	AGENA	TUG		1				1				1			3
	5C.	MAGNETOSPHERE EXPLORER	55	1 AU	4 x 6	600	11,000	AGENA	TUG			1				1				1		3
	5D.	MAGNETOSPHERE EXPLORER	90	1 AU	4 x 6	600	11,000	AGENA	TUG				1				1				1	3
	6.	ORBITING SOLAR OBSERVATORY	30	350	7 x 10	1,900	856	——— NONE ———			1											1
	7A.	GRAVITY/RELATIVITY EXP	85	300	5 x 7	1,500	692	——— NONE ———							1							1
	7B.	GRAVITY/RELATIVITY EXP	95	300	5 x 7	1,500	692	——— NONE ———													1	1
	8.	GRAVITY/RELATIVITY EXP	28.5	1 AU	4 x 5	500	11,000	AGENA	TUG			1						1				2
	9.	RADIO INTERFEROMETER	28.5	38646	12 x 15	6,000	13,660	CENTAUR	———			1										1
	10.	SOLAR ORBIT PAIR	30	19300	10 x 12	1,900	12,917	AGENA	TUG						1					1		2
	11.	SOLAR ORBIT PAIR	28.5	1 AU	10 x 12	1,900	11,000	AGENA	TUG						1					1		2
	12.	OPTICAL INTERFEROMETER	30	19300	7 x 10	3,500	12,917	———	TUG										2			2
	13A.	HEAO	30	230	10 x 34	19,700	468	——— NONE ———		1				1		1						3
	13B.	HIGH ENERGY STELLAR ASTR.	30	230	14 x 46	21,000	468	——— NONE ———					1					1		1		3
	14.	HESA REVISITS	30	230	14 x 13	3,500	468	——— NONE ———			2	2	2	2	2	2	2	2	2	2	2	22
	15A.	LST (STAR)	28.5	350	13 x 45	21,300	856	——— NONE ———				1				1						2
	15B.	LST (RAM)	28.5	350	14 x 60	30,000	856	——— NONE ———								1						1
	16.	LST (REVISITS)	28.5	350	14 x 13	3,500	856	——— NONE ———					2	2	2	1	2	2	2	2	2	17
	17.	LARGE SOLAR OBSERVATORY	30	350	14 x 54	27,000	856	——— NONE ———						1					2			3
	18.	(LSO REVISITS)	30	350	14 x 13	3,500	856	——— NONE ———							2	2	2	2	1	2	2	13
	19.	LARGE RADIO OBSERVATORY	30	350	14 x 30	19,300	856	——— NONE ———								1						1
	20.	(LRO REVISITS)	30	350	14 x 13	3,500	856	——— NONE ———									2	2	2	2	2	10
EARTH OBSERVATION	21.	POLAR EARTH OBS. SAT.	99.15	500	6 x 12	2,500	1,330	FW-4S	TUG	1	1	1	1	1	1	1	1	1	1	1	1	12
	22.	SYNCH. EARTH OBS. SAT.	0	19300	4 x 6	1,000	14,100	AGENA	TUG		1		1		1		1		1		1	6
	23.	EARTH PHYSICS SAT.	90	400	3.5 x 6.5	600	1,020	FW-4S	TUG		1	1	1	1		1		1		1		7
	24.	SYNCH. METEOROLOGICAL SAT.	0	19300	5 x 8	1,000	14,100	AGENA	———				1	1								2
	25.	TIROS	100.7	700	5 x 10	1,000	1,940	FW-4S	TUG			1				1					1	3
	26.	POLAR EARTH RESOURCES SAT.	99.15	500	6 x 12	2,500	1,330	———	TUG								2	4				6
	27.	SYNCH. EARTH RESOURCES SAT.	0	19300	4 x 6	1,000	14,100	AGENA	TUG			1	2	1				1	2			7
COMMUNICATION/ NAVIGATION	28.	APPLICATIONS TECH. SAT.	0	19300	15 x 20	7,950	14,100	CENTAUR	2 TUGS ②	1		1		1	1		1		1	1		7
	29.	SMALL APPLICATIONS SAT.	0	19300	6.5 x 12	600	14,100	AGENA	TUG	1	1	1	1	1	1	1	1	1	1	1	1	12
	30.	SMALL APPLICATIONS SAT.	90	3000 x 300	6.5 x 12	600	3,800	FW-4S	TUG	1	1	1	1	1	1	1	1	1	1	1	1	12
	31.	COOPERATIVE APPLICATIONS	0	19300	6.5 x 12	820	14,100	AGENA	———	1					1							2
	32.	COOPERATIVE APPLICATIONS	90	3000 x 300	6.5 x 12	820	3,800	FW-4S	TUG				1							1		2
	33.	MEDICAL NETWORK SAT.	0	19300	12 x 15	2,000	14,100	AGENA	———	2												2
	34.	EDUCATION BROADCAST SAT.	0	19300	10 x 19	2,145	14,100	AGENA	———		2											2
	35.	FOLLOW-ON SYSTEM DEMO.	0	19300	12 x 15	2,000	14,100	AGENA	TUG			2	2	2	2	2	2	2	2	2	2	20
	36.	TRACKING & DATA RELAY	0	19300	12 x 15	2,300	14,100	AGENA	TUG	1	2	1		2	1			2	1			10
	37.	PLANETARY RELAY SAT.	0	19300	10 x 20	1,000	14,100	———	———													0

① THEORETICAL MINIMUM, ONE-WAY, POINT-TO-POINT ΔV
② ASSEMBLED IN SPACE

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Figure 3.2.4-5 Program Level C Space Traffic Model Data (Part 1)

MISSION CATEGORY	NO.	MISSION TITLE	ORBIT INCL (°)	ORBIT ALT (nmi)	PAYLOAD DIA X L (FT)	MISSION PAYLOAD LB	ΔV ABOVE 100 X 100 FT/SEC ①	PROPULSIVE STAGE(S) ABOVE SHUTTLE 79-84	PROPULSIVE STAGE(S) ABOVE SHUTTLE 85-90	79	80	81	82	83	84	85	86	87	88	89	90	12-YEAR TOTAL
SORTIES	38.	GEN. SCIENCE RES. MODULE	55	200	14 x 54	27,500	360	—— NONE ——				2	3	4	4	3						16
	39.	GEN. APPL. MODULE	65	100	14 x 51	30,000	0	—— NONE ——				2	3	2	3	2	3		3	1		19
	40.	DED. SCI. & RES. MOD. ASTR.	55	200	14 x 54	29,500	360	—— NONE ——							1	3	4	5	4	5	5	27
	41.	DED. APPL. MOD. - EARTH OBS. PALLET TYPE MODULE	75	100	14 x 51	22,500	0	—— NONE ——							2	2	2	2	2	3	4	17
	42.	EARTH OBSERVATION	90	125	14 x 37	6,000	171	—— NONE ——			1	1	2									4
	43.	BIOLOGICAL RESEARCH	28.5	200	14 x 37	4,300	360	—— NONE ——		1												1
	44.	ASTRONOMY	28.5	200	14 x 37	5,700	360	—— NONE ——			2	2	2	1								7
	45.	FLUID MANAGEMENT	28.5	200	14 x 37	7,100	360	—— NONE ——			1			1								2
	46.	TELEOPERATOR	28.5	200	14 x 37	5,000	360	—— NONE ——			1											1
	47.	MANNED WORK PLATFORM	28.5	200	14 x 37	6,700	360	—— NONE ——				1										1
	48.	LARGE TELESCOPE MIRROR TEST	28.5	200	14 x 37	13,000	360	—— NONE ——		1												1
	49.	ASTRONAUT MAN. UNIT (AMU)	28.5	200	14 x 37	3,800	360	—— NONE ——			1											1
PLANETARY	50	VIKING	30	1.52 AU	10 x 12	7,700	15,400	CENTAUR	——	1		1										2
	51	MARS SAMPLE RETURN	30	1.52 AU	14 x 22.5	22,000	15,400	——	2 TUGS ②												2	2
	52	VENUS EXPLORER	30	.723 AU	5 x 12	1,000	13,400	AGENA	——		1											1
	53	VENUS RADAR MAPPING	30	.723 AU	10 x 12	7,900	13,400	CENTAUR	——				1									1
	54	VENUS EXPLORER LANDER	30	.723 AU	10 x 15	7,300	13,400	——	TUG							1			1			2
	55	JUPITER PIONEER ORBITER	30	5.20 AU	10 x 15	900	22,700	CENTAUR	——				2									2
	56	GRAND TOUR (JUN)	30	30.06 AU	10 x 12	1,500	25,900	2 CENTAURS ②	——	2												2
	57	JUPITER TOPS ORBITER/PROBE	30	5.20 AU	10 x 15	3,300	22,700	——	TUG							1		1				2
	58	URANUS TOPS ORBITER/PROBE	30	19.18 AU	10 x 15	3,700	24,000	——	TUG								1			1		2
	59	ASTEROID SURVEY	30	2.9 AU	10 x 35	27,000	13,400	2 CENTAURS ②	——						1							1
	60	COMET RENDEZVOUS	30	.34 AU	10 x 35	24,000	13,400	2 CENTAURS ②	2 TUGS ②				1			1						2
	60-3	SATURN ORBITER	30	9.54 AU	12 X 22.5	4,050	25,500 ③	——	——													0
	P-2	VENUS SURF. SAMPLE & RET.	30	.723 AU	15 X 170 ②	185,000	13,115 ③	——	——													0
	P-3	MARS SURF. SAMPLE & RET.	30	1.52 AU	15 X 124 ②	134,000	15,115 ③	——	——													0
	P-4	JUP ORB./PROBES & SAT. LANDERS	30	5.20 AU	15 X 65 ②	70,000	22,415 ③	——	——													0
SPACE STATION	61	STATION MODULES - CORE	55	270	14 x 40	20,000	592	—— NONE ——				1			1	1	3	2				8
	62	STATION MODULES - OTHERS	55	270	14 x 30	20,000	592	—— NONE ——				5				3						8
	63	CREW CARGO	55	270	14 x 30	20,000	592	—— NONE ——				1	6	6	6	6	8	8	8	8	8	65
	64	PHYSICS LAB	55	270	14 x 32	22,000	592	—— NONE ——						1					1			2
	65	COSMIC RAY LAB	55	270	14 x 52	30,000	592	—— NONE ——											1			1
	66	LIFE SCIENCE LAB	55	270	14 x 58	33,000	592	—— NONE ——				1		1		1					1	4
	67	EARTH OBSERVATIONS LAB	55	270	14 x 45	25,000	592	—— NONE ——				1		1		1					1	4
	68	COMM/NAVIGATION LAB	55	270	14 x 38	19,000	592	—— NONE ——						1		1					1	3
	69	SPACE MANUFACTURING LAB	55	270	14 x 45	25,000	592	—— NONE ——													1	1
NON-NASA	70	COMSAT SATELLITES	0	19300	6.5 x 12	1,420	14,100	AGENA	TUG	2	1	1		2	1	1			2	1		11
	71	U.S. DOMESTIC COMM	0	19300	10 x 19	2,145	14,100	AGENA	TUG	1	2	1	1	2	2	2	2	2	2	2	2	21
	72	FOREIGN DOMESTIC COMM.	28.5	19300	4 x 12	1,000	13,000	AGENA	TUG		2	6	2	2			4	5	2	1	2	26
	73	NAV & TRAFFIC CONTROL	29	30000 x 16000	5 x 8	700	13,948	AGENA	TUG	3	1	2		1		1		1		1		10
	74	NAV & TRAFFIC CONTROL	5	19300	5 x 8	700	13,400	AGENA	TUG		1	1		1		1		1		1		6
	75	TOS METEOROLOGICAL	100.7	700	5 x 6	1,000	1,940	FW-4S	TUG	1	1	1	1	1	1	1	1	1	1	1	1	12
	76	SYNC METEOROLOGICAL	0	19300	5 x 8	1,000	14,100	AGENA	TUG	1	1	1	1	1	1	1	1	1	1	1	1	12
	77	POLAR EARTH RESOURCES	99.15	500	12 x 15	2,500	1,330	FW-4S	TUG	4		4		4		4				6		22
	78	SYNCH EARTH RESOURCES	0	19300	6 x 6	1,000	14,100	——	TUG							4			4			8
	78-2	COMM SATS IN GENERAL	0	19300	8 X 10	850	14,100	——	——													0
	78-3	BROADCAST SAT INDIVIDUAL RECEP	0	19,300	10 X 12.5	2500	14,100	——	——													0
	78-4	BROADCAST SAT COMMUNITY RECEP	0	19300	8 X 10	1000	14,100	——	——													0
LUNAR	L-1	AUTO. LUNAR PROG. ORBITERS	28.5	100	15 X 31	1,600	10,400	——	——													0
	L-2	AUTO. LUNAR PROG. LANDERS	28.5	100	15 X 31	16,500	10,400	——	——													0
	L-3	MANNED SORTIE-CLASS MISS.	31.5	260	15 X 162 ②			——	——													0
	L-4	POST-SORTIE SURF. OPERATIONS	31.5	260	15 X 162 ②			——	——													0
TOTAL										31	33	55	46	54	46	62	51	57	58	56	50	599

① THEORETICAL MINIMUM, ONE-WAY, POINT-TO-POINT ΔV
② ASSEMBLED IN SPACE
③ ΔV ABOVE 180 X 180

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Figure 3.2.4-6 Program Level C Space Traffic Model Data (Part 2)

MISSION CATEGORY	NO.	MISSION TITLE	ORBIT INCL (°)	ORBIT ALT (nml)	PAYLOAD DIA X L (FT)	MISSION PAYLOAD LB	ΔV ABOVE 100 X 100 FT/SEC (1)	PROPULSIVE STAGE(S) ABOVE SHUTTLE 79-84 (2)	85-90	79	80	81	82	83	84	85	86	87	88	89	90	12-YEAR TOTAL
PHYSICS & ASTRONOMY	1.	ASTRONOMY EXPLORER	28.5	270	1.66 x 2.5	720	592	NONE		2		1	2	2	1		2	1	2	2		15
	2.	RADIO EXPLORER	28.5	19300	4.5 x 3.33	720	13,000	AGENA	TUG		2	1			1	2		1			2	9
	3A.	MAGNETOSPHERE EXPLORER	0	1800 x 180	4 x 8	1,200	11,783	AGENA	TUG	1				1				1				3
	3B.	MAGNETOSPHERE EXPLORER	28.5	1800 x 180	4 x 8	1,200	2,510	FW-4S	TUG		1				1				1			3
	3C.	MAGNETOSPHERE EXPLORER	55	1800 x 180	4 x 8	1,200	2,510	FW-4S	TUG			1				1				1		3
	3D.	MAGNETOSPHERE EXPLORER	90	1800 x 180	4 x 8	1,200	2,510	FW-4S	TUG				1				1				1	3
	4A.	MAGNETOSPHERE EXPLORER	0	20000 x 1000	5 x 8	1,000	11,158	AGENA	TUG	1				1				1				3
	4B.	MAGNETOSPHERE EXPLORER	28.5	20000 x 1000	5 x 8	1,000	10,720	AGENA	TUG		1				1				1			3
	4C.	MAGNETOSPHERE EXPLORER	55	20000 x 1000	5 x 8	1,000	10,720	AGENA	TUG			1				1				1		3
	4D.	MAGNETOSPHERE EXPLORER	90	20000 x 1000	5 x 8	1,000	10,720	AGENA	TUG				1				1				1	3
	5A.	MAGNETOSPHERE EXPLORER	0	1 AU	4 x 6	600	13,099	AGENA	TUG	1				1				1				3
	5B.	MAGNETOSPHERE EXPLORER	28.5	1 AU	4 x 6	600	11,000	AGENA	TUG		1				1				1			3
	5C.	MAGNETOSPHERE EXPLORER	55	1 AU	4 x 6	600	11,000	AGENA	TUG			1				1				1		3
	5D.	MAGNETOSPHERE EXPLORER	90	1 AU	4 x 6	600	11,000	AGENA	TUG				1				1				1	3
	6.	ORBITING SOLAR OBSERVATORY	30	350	7 x 10	1,900	856	NONE			1											1
	7A.	GRAVITY/RELATIVITY EXP	85	300	5 x 7	1,500	692	NONE							1							1
	7B.	GRAVITY/RELATIVITY EXP	95	300	5 x 7	1,500	692	NONE													1	1
	8.	GRAVITY/RELATIVITY EXP	28.5	1 AU	4 x 5	500	11,000	AGENA	TUG			1						1				2
	9.	RADIO INTERFEROMETER	28.5	38646	12 x 15	6,000	13,660	CENTAUR	———			1										1
	10.	SOLAR ORBIT PAIR	30	19300	10 x 12	1,900	12,917	AGENA	TUG						1					1		2
	11.	SOLAR ORBIT PAIR	28.5	1 AU	10 x 12	1,900	11,000	AGENA	TUG						1					1		2
	12.	OPTICAL INTERFEROMETER	30	19300	7 x 10	3,500	12,917	———	TUG										2			2
	13A.	HEAO	30	230	10 x 34	19,700	468	NONE		1				1		1						3
	13B.	HIGH ENERGY STELLAR ASTR.	30	230	14 x 46	21,000	468	NONE					1					1		1		3
	14.	HESA REVISITS	30	230	14 x 13	3,500	468	NONE			2	2	2	2	2	2	2	2	2	2	2	22
	15A.	LST (STAR)	28.5	350	13 x 45	21,300	856	NONE				1				1						2
	15B.	LST (RAM)	28.5	350	14 x 60	30,000	856	NONE								1						1
	16.	LST (REVISITS)	28.5	350	14 x 13	3,500	856	NONE					2	2	2	1	2	2	2	2	2	17
	17.	LARGE SOLAR OBSERVATORY	30	350	14 x 54	27,000	856	NONE						1					2			3
	18.	(LSO REVISITS)	30	350	14 x 13	3,500	856	NONE							2	2	2	2	1	2	2	13
	19.	LARGE RADIO OBSERVATORY	30	350	14 x 30	19,300	856	NONE								1						1
	20.	(LRO REVISITS)	30	350	14 x 13	3,500	856	NONE									2	2	2	2	2	10
EARTH OBSERVATION	21.	POLAR EARTH OBS. SAT.	99.15	500	6 x 12	2,500	1,330	FW-4S	TUG	1	1	1	1	1	1	1	1	1	1	1	1	12
	22.	SYNCH. EARTH OBS. SAT.	0	19300	4 x 6	1,000	14,100	AGENA	TUG		1		1		1		1		1		1	6
	23.	EARTH PHYSICS SAT.	90	400	3.5 x 6.5	600	1,020	FW-4S	TUG		1	1	1	1		1		1		1		7
	24.	SYNCH. METEOROLOGICAL SAT.	0	19300	5 x 8	1,000	14,100	AGENA	———				1	1								2
	25.	TIROS	100.7	700	5 x 10	1,000	1,940	FW-4S	TUG			1				1					1	3
	26.	POLAR EARTH RESOURCES SAT.	99.15	500	6 x 12	2,500	1,330	———	TUG								2	4				6
	27.	SYNCH. EARTH RESOURCES SAT.	0	19300	4 x 6	1,000	14,100	AGENA	TUG			1	2	1				1	2			7
COMMUNI-CATION/ NAVIGATION	28.	APPLICATIONS TECH. SAT.	0	19300	15 x 20	7,950	14,100	CENTAUR	2 TUGS (2)	1		1		1	1		1		1	1		7
	29.	SMALL APPLICATIONS SAT.	0	19300	6.5 x 12	600	14,100	AGENA	TUG	1	1	1	1	1	1	1	1	1	1	1	1	12
	30.	SMALL APPLICATIONS SAT.	90	3000 x 300	6.5 x 12	600	3,800	FW-4S	TUG	1	1	1	1	1	1	1	1	1	1	1	1	12
	31.	COOPERATIVE APPLICATIONS	0	19300	6.5 x 12	820	14,100	AGENA	———	1					1							2
	32.	COOPERATIVE APPLICATIONS	90	3000 x 300	6.5 x 12	820	3,800	FW-4S	TUG				1							1		2
	33.	MEDICAL NETWORK SAT.	0	19300	12 x 15	2,000	14,100	AGENA	———	2												2
	34.	EDUCATION BROADCAST SAT.	0	19300	10 x 19	2,145	14,100	AGENA	———		2											2
	35.	FOLLOW-ON SYSTEM DEMO.	0	19300	12 x 15	2,000	14,100	AGENA	TUG			2	2	2	2	2	2	2	2	2	2	20
	36.	TRACKING & DATA RELAY	0	19300	12 x 15	2,300	14,100	AGENA	TUG	1	2	1		2	1			2	1			10
	37.	PLANETARY RELAY SAT.	0	19300	10 x 20	1,000	14,100	AGENA	TUG	2	1				1	2				1	2	9

(1) THEORETICAL MINIMUM, ONE-WAY, POINT-TO-POINT ΔV

(2) GB AND SB TUG ALSO TO BE ANALYZED FOR THIS PERIOD

(3) ASSEMBLED IN SPACE

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Figure 3.2.4-7 Program Level D Space Traffic Model Data (Part 1)

MISSION CATEGORY	NO.	MISSION TITLE	ORBIT INCL (°)	ORBIT ALT (nmi)	PAYLOAD DIA X L (FT)	MISSION PAYLOAD LB	ΔV ABOVE 100 X 100 FT/SEC ①	PROPULSIVE STAGE(S) ABOVE SHUTTLE 79-84 ⑥	PROPULSIVE STAGE(S) ABOVE SHUTTLE 85-90	79	80	81	82	83	84	85	86	87	88	89	90	12-YEAR TOTAL
SORTIES	38.	GEN. SCIENCE RES. MODULE	55	200	14 x 54	27,500	360	—— NONE ——				2	3	4	4	3						16
	39.	GEN. APPL. MODULE	65	100	14 x 51	30,000	0	—— NONE ——				2	3	2	3	2	3		3	1		19
	40.	DED. SCI. & RES. MOD. ASTR.	55	200	14 x 54	29,500	360	—— NONE ——							1	3	4	5	4	5	5	27
	41.	DED. APPL. MOD. - EARTH OBS. PALLET TYPE MODULE	75	100	14 x 51	22,500	0	—— NONE ——							2	2	2	2	2	3	4	17
	42.	EARTH OBSERVATION	90	125	14 x 37	6,000	171	—— NONE ——			1	1	2									4
	43.	BIOLOGICAL RESEARCH	28.5	200	14 x 37	4,300	360	—— NONE ——		1												1
	44.	ASTRONOMY	28.5	200	14 x 37	5,700	360	—— NONE ——			2	2	2	1								7
	45.	FLUID MANAGEMENT	28.5	200	14 x 37	7,100	360	—— NONE ——			1			1								2
	46.	TELEOPERATOR	28.5	200	14 x 37	5,000	360	—— NONE ——			1											1
	47.	MANNED WORK PLATFORM	28.5	200	14 x 37	6,700	360	—— NONE ——				1										1
	48.	LARGE TELESCOPE MIRROR TEST	28.5	200	14 x 37	13,000	360	—— NONE ——		1												1
	49.	ASTRONAUT MAN. UNIT (AMU)	28.5	200	14 x 37	3,800	360	—— NONE ——			1											1
PLANETARY	50	VIKING	30	1.52 AU	10 x 12	7,700	15,400	CENTAUR	——②	1		1										2
	51	MARS SAMPLE RETURN	30	1.52 AU	14 x 22.5	22,000	15,400	——	2 TUGS												2	2
	52	VENUS EXPLORER	30	.723 AU	5 x 12	1,000	13,400	AGENA	TUG		1											1
	53	VENUS RADAR MAPPING	30	.723 AU	10 x 12	7,900	13,400	CENTAUR	——				1									1
	54	VENUS EXPLORER LANDER	30	.723 AU	10 x 15	7,300	13,400	——	TUG							1			1			2
	55	JUPITER PIONEER ORBITER	30	5.20 AU	10 x 15	900	22,700	CENTAUR	——				2									2
	56	GRAND TOUR (JUN)	30	30.06 AU	10 x 12	1,500	25,900	2 CENTAURS ②	TUG	2												2
	57	JUPITER TOPS ORBITER/PROBE	30	5.20 AU	10 x 15	3,300	22,700	——	TUG							1		1				2
	58	URANUS TOPS ORBITER/PROBE	30	19.18 AU	10 x 15	3,700	24,000	——	TUG								1			1		2
	59	ASTEROID SURVEY	30	2.9 AU	10 x 35	27,000	13,400	2 CENTAURS ②	——②						1							1
	60	COMET RENDEZVOUS	30	.34 AU	10 x 35	24,000	13,400	2 CENTAURS ②	2 TUGS				1			1						2
	60-3	SATURN ORBITER	30	9.54 AU	12 x 22.5	4,050	25,500 ③	——	TUG											1		1
	P-2	VENUS SURF. SAMPLE & RET.	30	.723 AU	15 x 170 ②	185,000	13,115 ③	——	——													0
	P-3	MARS SURF. SAMPLE & RET.	30	1.52 AU	15 x 124 ②	134,000	15,115 ③	——	——													0
	P-4	JUP ORB./PROBES & SAT. LANDERS	30	5.20 AU	15 x 65 ②	70,000	22,415 ③	——	——													0
SPACE STATION	61	STATION MODULES-CORE	55	270	14 x 40	20,000	592	—— NONE ——				1			1	1	3	2				8
	62	STATION MODULES - OTHERS	55	270	14 x 30	20,000	592	—— NONE ——				5				3						8
	63	CREW CARGO	55	270	14 x 30	20,000	592	—— NONE ——				1	6	6	6	6	8	8	8	8	8	65
	64	PHYSICS LAB	55	270	14 x 32	22,000	592	—— NONE ——						1					1			2
	65	COSMIC RAY LAB	55	270	14 x 52	30,000	592	—— NONE ——											1			1
	66	LIFE SCIENCE LAB	55	270	14 x 58	33,000	592	—— NONE ——				1		1		1					1	4
	67	EARTH OBSERVATIONS LAB	55	270	14 x 45	25,000	592	—— NONE ——				1		1		1					1	4
	68	COMM/NAVIGATION LAB	55	270	14 x 38	19,000	592	—— NONE ——						1		1					1	3
	69	SPACE MANUFACTURING LAB	55	270	14 x 45	25,000	592	—— NONE ——													1	1
NON-NASA	70	COMSAT SATELLITES	0	19300	6.5 x 12	1,420	14,100	AGENA	TUG	2	1	1		2	1	1			2	1		11
	71	U.S. DOMESTIC COMM	0	19300	10 x 19	2,145	14,100	AGENA	TUG	1	2	1	1	2	2	2	2	2	2	2	2	21
	72	FOREIGN DOMESTIC COMM.	28.5	19300	4 x 12	1,000	13,000	AGENA	TUG		2	6	2	2			4	5	2	1	2	26
	73	NAV & TRAFFIC CONTROL	29	30000 x 16000	5 x 8	700	13,948	AGENA	TUG	3	1	2		1		1		1		1		10
	74	NAV & TRAFFIC CONTROL	5	19300	5 x 8	700	13,400	AGENA	TUG		1	1		1		1		1		1		6
	75	TOS METEOROLOGICAL	100.7	700	5 x 6	1,000	1,940	FW-4S	TUG	1	1	1	1	1	1	1	1	1	1	1	1	12
	76	SYNC METEOROLOGICAL	0	19300	5 x 8	1,000	14,100	AGENA	TUG	1	1	1	1	1	1	1	1	1	1	1	1	12
	77	POLAR EARTH RESOURCES	99.15	500	12 x 15	2,500	1,330	FW-4S	TUG	4		4		4		4				6		22
	78	SYNCH EARTH RESOURCES	0	19300	6 x 6	1,000	14,100	——	TUG							4			4			8
	78-2	COMM. SATS. IN GENERAL	0	19300	8 x 10	850	14,100	AGENA	TUG	4	4	4	4	4	4	4	4	4	4	4	4	48
	78-3	BROADCAST SAT. IND. RECEPTION	0	19300	10 x 12.5	2,500	14,100	CENTAUR	TUG	2	2	2	2	2	2	2	2	2	2	2	2	24
	78-4	BROADCAST SAT. COMM. RECEP	0	19300	8 x 10	1,000	14,100	AGENA	TUG	2	2	2	2	2	2	2	2	2	2	2	2	24
LUNAR	L-1	AUTO. LUNAR PROG. ORBITERS	28.5	100	15 x 31	1,600	10,400	AGENA	——	1	1		1	1	1							5
	L-2	AUTO. LUNAR PROG. LANDERS	28.5	100	15 x 31	16,500	10,400	CENTAUR	——	1	1		1	1	1							5
	L-3	MANNED SORTIE-CLASS MISS.	31.5	260	15 x 162 ②			——	RNS/CIS								2	2	2			6
	L-4	POST-SORTIE SURF. OPERATIONS	31.5	260	15 x 162 ②			——	RNS/CLS											2	2	4
TOTAL										43	44	63	56	64	57	72	61	67	68	68	62	725

① THEORETICAL MINIMUM, ONE-WAY, POINT-TO-POINT ΔV ③ ΔV ABOVE 180 x 180 nmi ⑥ GB AND SB TUG ALSO TO BE ANALYZED FOR THIS PERIOD
② ASSEMBLED IN SPACE

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Figure 3.2.4-8 Program Level D Space Traffic Model Data (Part 2)

MISSION CATEGORY	NO.	MISSION TITLE	ORBIT INCL (°)	ORBIT ALT (nmi)	PAYLOAD DIA X L (FT)	MISSION PAYLOAD LB	ΔV ABOVE 100 X 100 FT/SEC ①	PROPULSIVE STAGE(S) ABOVE SHUTTLE 79 - 84 ②	PROPULSIVE STAGE(S) ABOVE SHUTTLE 85 - 90	79	80	81	82	83	84	85	86	87	88	89	90	12-YEAR TOTAL
PHYSICS & ASTRONOMY	1.	ASTRONOMY EXPLORER	28.5	270	1.7 x 2.5	720	592	NONE		2		1	2	2	1		2	1	2	2		15
	2.	RADIO EXPLORER	28.5	19300	4.5 x 3.3	720	13,000	AGENA	TUG		2	1			1	2		1			2	9
	3A.	MAGNETOSPHERE EXPLORER	0	1800 x 180	4 x 8	1,200	11,783	AGENA	TUG	1				1				1				3
	3B.	MAGNETOSPHERE EXPLORER	28.5	1800 x 180	4 x 8	1,200	2,510	FW-4S	TUG		1				1				1			3
	3C.	MAGNETOSPHERE EXPLORER	55	1800 x 180	4 x 8	1,200	2,510	FW-4S	TUG			1				1				1		3
	3D.	MAGNETOSPHERE EXPLORER	90	1800 x 180	4 x 8	1,200	2,510	FW-4S					1				1				1	3
	4A.	MAGNETOSPHERE EXPLORER	0	20000 x 1000	5 x 8	1,000	11,158	TUG		1				1				1				3
	4B.	MAGNETOSPHERE EXPLORER	28.5	20000 x 1000	5 x 8	1,000	10,720	TUG			1				1				1			3
	4C.	MAGNETOSPHERE EXPLORER	55	20000 x 1000	5 x 8	1,000	10,720	TUG				1				1				1		3
	4D.	MAGNETOSPHERE EXPLORER	90	20000 x 1000	5 x 8	1,000	10,720	TUG					1				1				1	3
	5A.	MAGNETOSPHERE EXPLORER	0	1 AU	4 x 6	600	13,099	TUG		1				1				1				3
	5B.	MAGNETOSPHERE EXPLORER	28.5	1 AU	4 x 6	600	11,000	TUG			1				1				1			3
	5C.	MAGNETOSPHERE EXPLORER	55	1 AU	4 x 6	600	11,000	TUG				1				1				1		3
	5D.	MAGNETOSPHERE EXPLORER	90	1 AU	4 x 6	600	11,000	TUG					1				1				1	3
	6.	ORBITING SOLAR OBSERVATORY	30	350	7 x 10	1,900	856	NONE			1											1
	7A.	GRAVITY/RELATIVITY EXP	85	300	5 x 7	1,500	692	NONE							1							1
	7B.	GRAVITY/RELATIVITY EXP	95	300	5 x 7	1,500	692	NONE													1	1
	8.	GRAVITY/RELATIVITY EXP	28.5	1 AU	4 x 5	500	11,000	AGENA	TUG			1						1				2
	9.	RADIO INTERFEROMETER	28.5	38646	12 x 15	6,000	13,660	CENTAUR	—			1										1
	10.	SOLAR ORBIT PAIR	30	19300	10 x 12	1,900	12,917	AGENA	TUG						1					1		2
	11.	SOLAR ORBIT PAIR	28.5	1 AU	10 x 12	1,900	11,000	AGENA	TUG						1					1		2
	12.	OPTICAL INTERFEROMETER	30	19300	7 x 10	3,500	12,917	—	TUG										2			2
	13A.	HEAO	30	230	10 x 34	19,700	468	NONE		1				1		1						3
	13B.	HIGH ENERGY STELLAR ASTR.	30	230	14 x 46	21,000	468	NONE					1					1		1		3
	14.	HESA REVISITS	30	230	14 x 13	3,500	468	NONE			2	2	2	2	2	2	2	2	2	2	2	22
	15A.	LST (STAR)	28.5	350	13 x 45	21,300	856	NONE				1				1						2
	15B.	LST (RAM)	28.5	350	14 x 60	30,000	856	NONE								1						1
	16.	LST (REVISITS)	28.5	350	14 x 13	3,500	856	NONE					2	2	2	1	2	2	2	2	2	17
	17.	LARGE SOLAR OBSERVATORY	30	350	14 x 54	27,000	856	NONE						1					2			3
	18.	(LSO REVISITS)	30	350	14 x 13	3,500	856	NONE							2	2	2	2	1	2	2	13
	19.	LARGE RADIO OBSERVATORY	30	350	14 x 30	19,300	856	NONE								1						1
	20.	(LRO REVISITS)	30	350	14 x 13	3,500	856	NONE									2	2	2	2	2	10
EARTH OBSERVATION	21.	POLAR EARTH OBS. SAT.	99.15	500	6 x 12	2,500	1,330	FW-4S	TUG	1	1	1	1	1	1	1	1	1	1	1	1	12
	22.	SYNCH. EARTH OBS. SAT.	0	19300	4 x 6	1,000	14,100	AGENA	TUG		1		1		1		1		1		1	6
	23.	EARTH PHYSICS SAT.	90	400	3.5 x 6.5	600	1,020	FW-4S	TUG		1	1	1	1		1		1		1		7
	24.	SYNCH. METEOROLOGICAL SAT.	0	19300	5 x 8	1,000	14,100	AGENA	—				1	1								2
	25.	TIROS	100.7	700	5 x 10	1,000	1,940	FW-4S	TUG			1				1					1	3
	26.	POLAR EARTH RESOURCES SAT.	99.15	500	6 x 12	2,500	1,330	—	TUG								2	4				6
	27.	SYNCH. EARTH RESOURCES SAT.	0	19300	4 x 6	1,000	14,100	AGENA	TUG			1	2	1				1	2			7
COMMUNI-CATION/ NAVIGATION	28.	APPLICATIONS TECH. SAT.	0	19300	15 x 20	7,950	14,100	CENTAUR	2 TUGS ③	1		1		1	1		1		1	1		7
	29.	SMALL APPLICATIONS SAT.	0	19300	6.5 x 12	600	14,100	AGENA	TUG	1	1	1	1	1	1	1	1	1	1	1	1	12
	30.	SMALL APPLICATIONS SAT.	90	3000 x 300	6.5 x 12	600	3,800	FW-4S	TUG	1	1	1	1	1	1	1	1	1	1	1	1	12
	31.	COOPERATIVE APPLICATIONS	0	19300	6.5 x 12	820	14,100	AGENA	—	1					1							2
	32.	COOPERATIVE APPLICATIONS	90	3000 x 300	6.5 x 12	820	3,800	FW-4S	TUG				1							1		2
	33.	MEDICAL NETWORK SAT.	0	19300	12 x 15	2,000	14,100	AGENA	—	2												2
	34.	EDUCATION BROADCAST SAT.	0	19300	10 x 19	2,145	14,100	AGENA	—		2											2
	35.	FOLLOW-ON SYSTEM DEMO.	0	19300	12 x 15	2,000	14,100	AGENA	TUG			2	2	2	2	2	2	2	2	2	2	20
	36.	TRACKING & DATA RELAY	0	19300	12 x 15	2,300	14,100	AGENA	TUG	1	2	1		2	1			2	1			10
	37.	PLANETARY RELAY SAT.	0	19300	10 x 20	1,000	14,100	AGENA	TUG	2	1				1	2				1	2	9

① THEORETICAL MINIMUM, ONE-WAY, POINT-TO-POINT ΔV

② GB AND SB TUG ALSO TO BE ANALYZED FOR THIS PERIOD

③ ASSEMBLED IN SPACE

REVISED 22 NOV '71

Figure 3.2.4- 9 Program Level E Space Traffic Model (Part 1)

Space Division
North American Rockwell

MISSION CATEGORY	NO.	MISSION TITLE	ORBIT INCL (°)	ORBIT ALT (nmi)	PAYLOAD DIA X L (FT)	MISSION PAYLOAD LB	ΔV ABOVE 100 X 100 FT/SEC ①	PROPULSIVE STAGE(S) ABOVE SHUTTLE 79 - 84 ⑥	PROPULSIVE STAGE(S) ABOVE SHUTTLE 85 - 90	79	80	81	82	83	84	85	86	87	88	89	90	12-YEAR TOTAL
SORTIES	38.	GEN. SCIENCE RES. MODULE	55	200	14 x 54	27,500	360	—— NONE	——			2	3	4	4	3						16
	39.	GEN. APPL. MODULE	65	100	14 x 51	30,000	0	—— NONE	——			2	3	2	3	2	3		3	1		19
	40.	DED. SCI. & RES. MOD. ASTR.	55	200	14 x 54	29,500	360	—— NONE	——						1	3	4	5	4	5	5	27
	41.	DED. APPL. MOD. - EARTH OBS. PALLET TYPE MODULE	75	100	14 x 51	22,500	0	—— NONE	——						2	2	2	2	2	3	4	17
	42.	EARTH OBSERVATION	90	125	14 x 37	6,000	171	—— NONE	——		1	1	2									4
	43.	BIOLOGICAL RESEARCH	23.5	200	14 x 37	4,300	360	—— NONE	——	1												1
	44.	ASTRONOMY	23.5	200	14 x 37	5,700	360	—— NONE	——		2	2	2	1								7
	45.	FLUID MANAGEMENT	23.5	200	14 x 37	7,100	360	—— NONE	——		1			1								2
	46.	TELEOPERATOR	23.5	200	14 x 37	5,000	360	—— NONE	——		1											1
	47.	MANNED WORK PLATFORM	23.5	200	14 x 37	6,700	360	—— NONE	——			1										1
	48.	LARGE TELESCOPE MIRROR TEST	23.5	200	14 x 37	13,000	360	—— NONE	——	1												1
	49.	ASTRONAUT MAN. UNIT (AMU)	23.5	200	14 x 37	3,800	360	—— NONE	——		1											1
PLANETARY	50	VIKING	30	1.52 AU	10 x 12	7,700	15,400	CENTAUR	——	1		1										2
	51	MARS SAMPLE RETURN	30	1.52 AU	14 x 22.5	22,000	15,400	——	——													0
	52	VENUS EXPLORER	30	.723 AU	5 x 12	1,000	13,400	AGENA	——		1											1
	53	VENUS RADAR MAPPING	30	.723 AU	10 x 12	7,900	13,400	CENTAUR	——				1									1
	54	VENUS EXPLORER LANDER	30	.723 AU	10 x 15	7,300	13,400	——	——													0
	55	JUPITER PIONEER ORBITER	30	5.20 AU	10 x 15	900	22,700	TUG	TUG				2									2
	56	GRAND TOUR (JUN)	30	30.06 AU	10 x 12	1,500	25,900	2 CENTAURS ②	——	2												2
	57	JUPITER TOPS ORBITER/PROBE	30	5.20 AU	10 x 15	3,300	22,700	——	TUG							1						1
	58	URANUS TOPS ORBITER/PROBE	30	19.18 AU	10 x 15	3,700	24,000	——	TUG								1			1		2
	59	ASTEROID SURVEY	30	2.9 AU	10 x 35	27,000	13,400	2 CENTAURS ②	——						1							1
	60	COMET RENDEZVOUS	30	.34 AU	10 x 35	24,000	13,400	2 CENTAURS ②	2 TUGS ②				1			1						2
	60-3	SATURN ORBITER	30	9.54 AU	12 x 22.5	4,050	25,500 ③	——	TUG											1		1
	P-2	VENUS SURF. SAMPLE & RET.	30	.723 AU	15 x 170 ②	185,000	13,115 ③	——	RNS/CIS							1						1
	P-3	MARS SURF. SAMPLE & RET.	30	1.52 AU	15 x 124 ②	134,000	15,115 ③	——	!						1				1			2
	P-4	JUP. ORB./PROBES & SAT. LANDERS	30	5.20 AU	15 x 65 ②	70,000	22,415 ③	——	RNS/CIS									1			1	2
SPACE STATION	61	STATION MODULES - CORE	55	270	14 x 40	20,000	592	—— NONE	——			1			1	1	3	2				8
	62	STATION MODULES - OTHERS	55	270	14 x 30	20,000	592	—— NONE	——			5				3						8
	63	CREW CARGO	55	270	14 x 30	20,000	592	—— NONE	——			1	6	6	6	6	8	8	8	8	8	65
	64	PHYSICS LAB	55	270	14 x 32	22,000	592	—— NONE	——					1					1			2
	65	COSMIC RAY LAB	55	270	14 x 52	30,000	592	—— NONE	——										1			1
	66	LIFE SCIENCE LAB	55	270	14 x 58	33,000	592	—— NONE	——			1		1		1					1	4
	67	EARTH OBSERVATIONS LAB	55	270	14 x 45	25,000	592	—— NONE	——			1		1		1					1	4
	68	COMM/NAVIGATION LAB	55	270	14 x 38	19,000	592	—— NONE	——					1		1					1	3
	69	SPACE MANUFACTURING LAB	55	270	14 x 45	25,000	592	—— NONE	——												1	1
NON-NASA	70	COMSAT SATELLITES	0	19300	6.5 x 12	1,420	14,100	AGENA	TUG	2	1	1		2	1	1			2	1		11
	71	U.S. DOMESTIC COMM	0	19300	10 x 19	2,145	14,100	AGENA	TUG	1	2	1	1	2	2	2	2	2	2	2	2	21
	72	FOREIGN DOMESTIC COMM.	28.5	19300	4 x 12	1,000	13,000	AGENA	TUG		2	6	2	2			4	5	2	1	2	26
	73	NAV & TRAFFIC CONTROL	29	30000 x 16000	5 x 8	700	13,948	AGENA	TUG	3	1	2		1		1		1		1		10
	74	NAV & TRAFFIC CONTROL	5	19300	5 x 8	700	13,400	AGENA	TUG		1	1		1		1		1		1		6
	75	TOS METEOROLOGICAL	100.7	700	5 x 6	1,000	1,940	FW-4S	TUG	1	1	1	1	1	1	1	1	1	1	1	1	12
	76	SYNC METEOROLOGICAL	0	19300	5 x 8	1,000	14,100	AGENA	TUG	1	1	1	1	1	1	1	1	1	1	1	1	12
	77	POLAR EARTH RESOURCES	99.15	500	12 x 15	2,500	1,330	FW-4S	TUG	4		4		4		4				6		22
	78	SYNCH EARTH RESOURCES	0	19300	6 x 6	1,000	14,100		TUG							4			4			8
	78-2	COMM SATS IN GENERAL	0	19300	8 X 10	850	14,100	AGENA	TUG	4	4	4	4	4	4	4	4	4	4	4	4	48
	78-3	BROADCAST SAT INDIVIDUAL RECEP	0	19300	10 X 12.5	2,500	14,100	CENTAUR	TUG	2	2	2	2	2	2	2	2	2	2	2	2	24
	78-4	BROADCAST SAT COMMUNITY RECEP	0	19300	8 X 10	1,000	14,100	AGENA	TUG	2	2	2	2	2	2	2	2	2	2	2	2	24
LUNAR	L-1	AUTO. LUNAR PROG. ORBITERS	28.5	100	15 x 31	1,600	10,400	AGENA	TUG	1	1		1	1	1							5
	L-2	AUTO. LUNAR PROG. LANDERS	28.5	100	15 x 31	16,500	10,400	CENTAUR	TUG	1	1		1	1	1							5
	L-3	MANNED SORTIE-CLASS MISS.	31.5	260	15 x 162 ②			——	RNS/CIS								2	2	2			6
	L-4	POST-SORTIE SURF. OPERATIONS	31.5	260	15 x 162 ②			——	RNS/CIS											2	2	4
TOTAL										43	44	63	56	64	58	72	61	67	68	68	61	725

① THEORETICAL MINIMUM, ONE-WAY, POINT-TO-POINT ΔV
② ASSEMBLED IN SPACE
③ ΔV ABOVE 180 X 180 nmi
⑥ GB & SB TUG ALSO TO BE ANALYZED FOR THIS PERIOD

REVISED

Figure 3.2.4-10 Program Level E Space Traffic Model (Part 2)

shuttle orbiter without a payload propulsive stage are identified by the term "None" in the propulsive stage column.

Examination of the space traffic model data for Program Level A reveals that this program level does not include a space station and its associated placement or retrieval missions. Only expendable (nonreusable) payload propulsive stages are shown for the entire 12-year program, which contains one-half of the Fleming Model earth orbital placement missions plus all of the planetary missions.

Program Level B, described in Figures 3.2.4-3 and 3.2.4-4, contains all of the placements in Program Level A plus one-half of the Fleming Model placements not included in Level A. In addition, the space station and its associated missions are introduced in 1982; and the reusable tug is considered to be available in 1985.

Program Level C, described in Figures 3.2.4-5 and 3.2.4-6 contains all of the placements in the Fleming Model (Program Level B plus the Fleming Model missions not included in Level B). It also differs slightly from Program Level B in that the space station is introduced one year earlier (in 1981), but the reusable tug availability date (1985) is the same as before.

Program Level D, described in Figures 3.2.4-7 and 3.2.4-8, contains all of the placements in Program Level C plus 106 additional communication/navigation, planetary and non-NASA placement missions (Nos. 37, 60-3, 78-2, 78-3 and 78-4). Also added are 10 automated lunar program missions (Nos. L-1 and L-2) and 10 manned lunar missions (Nos. L-3 and L-4). The latter are performed with either the CIS or the RNS, which are assumed to be available in 1986.

Program Level E, described in Figures 3.2.4-9 and 3.2.4-10, contains all of the placements in Program Level D minus five of the planetary mission placements (Nos. 51, 54 and 57). These have been replaced by five augmented planetary missions (Nos. P-2, P-3 and P-4) which are performed with either the CIS or the RNS beginning in 1984.

3.3 TIME-PHASED PROPELLANT REQUIREMENTS

3.3.1 Mission Orbital Propellant Requirements

Following the definition of payload propulsive stage characteristics and placement mission delta-V requirements, propellant requirements for each placement and vehicle combination could be established. Individual mission propellant requirements were calculated with the following equation:

$$W_p = \left(e^{\frac{\Delta V}{g\, I_{sp}}} - 1\right)\left(W_{B.O.} + W_{P.L.}\right)$$

where W_p = propellant requirement, pounds

ΔV = velocity increment, ft/sec

$g = 32.2 \text{ ft/sec}^2$

I_{sp} = specific impulse of payload propulsive stage, seconds (from Section 3.2.2)

$W_{B.O.}$ = payload propulsive stage burnout weight, pounds (from Figure 3.2.2-1)

$W_{P.L.}$ = scientific payload weight, pounds (from Figures 3.2.4-1 through -10)

This equation yields the propellant requirement for a one-way trip; and for placement missions performed with a recoverable propulsive stage, separate calculations were made for the outbound and inbound portions of the mission. For the outbound portion of a round-trip mission, the payload propulsive stage burnout weight ($W_{B.O.}$) includes the weight of propellant required for the inbound leg; and the $W_{P.L.}$ term goes to zero for the return trip of the propulsive stage to the initial orbit.

The velocity increments used in the calculation of propellant requirements were those shown in the NASA Payload List (Table 3.1-1) with a 10 percent allowance (for phasing, rendezvous, and other orbital maneuvers) for missions with a theoretical one-way point-to-point delta-V requirement of less than 10,000 feet per second. For missions with a delta-V requirement of 10,000 feet per second or greater, propellant requirement calculations were made with a 5 percent delta-V allowance.

The resulting delta-V values and the corresponding payload propulsive stage propellant requirements are shown in Table 3.3.1-1 for an expendable stage, the ground-based tug, and the space-based tug for each mission employing these vehicles. Propellant requirements for missions performed with either the CIS or the RNS are shown in Table 3.3.1-2. Examination of Table 3.3.1-1 reveals that a number of missions require 2 Centaurs and/or 2 tugs for payload placements because total mission delta-V requirements exceed the capability of a single stage. Propellant requirements for such two-stage vehicle arrangements were established as follows:

<u>Two-Stage Expendable</u>

Solve for ΔV_2:

$$\frac{W_{P.L.}}{W_{P2} + W_i + W_{P.L.}} = 1 - \frac{W_{P2} + W_i}{W_{P2}} \left[1 - e^{-\frac{\Delta V_2}{g I_{sp}}} \right]$$

Solve for ΔV_1:

$$\Delta V_1 = \Delta V_T - \Delta V_2$$

Table 3.3.1-1 Payload Propulsive
Stage Propellant Requirements

Mission No.	Δ V ① ft/sec	Expendable Stage		GB Tug Propellant pounds	SB Tug Propellant pounds
			Propellant pounds		
2	13650	AGENA	6590	37937	54543
3A	12372	AGENA	6758	31540	44987
3B,3C,3D	2761	FW-4S	--	3441	4817
4A	11716	AGENA	5671	28093	40109
4B,4C,4D	11256	AGENA	5296	26011	37104
5A	13754	AGENA	6306	38382	55268
5B,5C,5D	11550	AGENA	4611	26869	38536
8	11550	AGENA	4381	26755	38419
9	14343	CENTAUR	17444	50596	69370
10	13563	AGENA	10136	39132	55544
11	11550	AGENA	7609	28358	40057
12	13563	CENTAUR	12025	41452	57917
21	1463	FW-4S	--	1804	2470
22	14805	AGENA	8713	45823	65834
23	1122	FW-4S	--	1208	1704
24	14805	AGENA	8713	45823	65834
25	2134	FW-4S	--	2520	3535
26	1463	FW-4S	--	1804	2470
27	14805	AGENA	8713	45823	65834
28	14805	CENTAUR	21891	57359	78800 ③
29	14805	AGENA	7260	45159	65154
30	4180	FW-4S	--	5552	7865
31	14805	AGENA	8059	45524	65528
32	4180	FW-4S	--	5622	7936
33	14805	AGENA	12343	47483	67533
34	14805	AGENA	12869	47723	67780
35	14805	AGENA	12343	47483	67533
36	14805	AGENA	13432	47981	68043

Table 3.3.1-1 Payload Propulsive
Stage Propellant Requirements (cont'd)

Mission No.	ΔV ft/sec	Expendable Stage		GB Tug Propellant pounds	SB Tug Propellant pounds
			Propellant pounds		
37	14805	AGENA	8713	45823	65834
50	16170	CENTAUR	25195	71511 (3)	99606 (3)
51	16170	2 CENTAURS (2)	57147	104296 (3)	134100 (3)
52	14070	AGENA	7898	40936	58724
53	14070	CENTAUR	20106	51519	69555
54	14070	CENTAUR	19101	50598	68613
55	23835	CENTAUR	21485	31294 (4)	43813 (4)
56	27195	2 CENTAURS (2)	33391	44200 (4)	60920 (4)
57	23835	2 CENTAURS (2)	32937	40487 (4)	53286 (4)
58	25200	2 CENTAURS (2)	39573	47021 (4)	61458 (4)
59	14070	2 CENTAURS (2)	54042	84946 (3)	105200 (3)
60	14070	2 CENTAURS (2)	48719	79570 (3)	99500 (3)
60-3	26775	--	--	55085 (4)	71600 (4)
70	14805	AGENA	10237	46520	66548
71	14805	AGENA	12869	47723	67780
72	13650	AGENA	7460	38347	54963
73	14645	AGENA	7464	44232	63729
74	14070	AGENA	6911	40476	58253
75	2134	FW-4S	--	2520	3535
76	14805	AGENA	8713	45823	65834
77	1463	FW-4S	--	1804	2470
78	14805	AGENA	8713	45823	65834
78-2	14805	AGENA	8168	45574	65600
78-3	14805	CENTAUR	11990	48312	68400
78-4	14805	AGENA	8713	45823	65800
L-1	10920	AGENA	6300	25240	35724
L-2	10920	CENTAUR	23860	41017	51837

1 Theoretical minimum, one-way, point-to-point ΔV plus 5% or 10% allowance.
2 Assembled in space.
3 Requires two tugs in tandem, assembled in space.
4 Tug cannot be recovered.

Table 3.3.1-2 CIS/RNS Mission
Propellant Requirements

Mission	ΔV (ft/sec)	CIS Propellant Weight (pounds)	RNS Propellant Weight (pounds)	Payload Propellant Weight (pounds)
P-2	13770	498000	195000	
P-3	15870	498000	195000	
P-4	23535	755000	244000	
L-3	25440	990000* 1042000**	300000* 354000**	85000
L-4	25440	990000* 1042000**	300000* 354000**	85000

*Mode 1 Operation
**Mode 2 Operation

Solve for W_{P1}:

$$\frac{W_{u1}}{W_o} = 1 - \frac{W_{P1} + W_i}{W_{P1}} \left(1 - e^{-\frac{\Delta V_1}{gI_{sp}}} \right)$$

Where

ΔV_1 is the ΔV expended by the first stage.

ΔV_2 is the ΔV expended by the second stage.

$W_{u1} = W_{P2} + W_i + W_{P.L.}$

$W_o = W_{P1} + 2W_i + W_{P2} + W_{P.L.}$

W_{P1} = propellant in first stage

W_{P2} = propellant in second stage

W_i = inert weight of one stage

Two-Stage Reusable

$$\Delta V_2 = -g\, I_{sp}\ \ln \left[1 - \frac{K_2\, W_{p2}}{A} \right]$$

where ΔV_2 = second stage outbound ΔV

K_2 = percent W_{P2} used in the outbound leg

$$= 1 - \frac{K_{11}\, W_i}{(1 - K_{11}) W_{P2}}$$

$A = W_{P.L.} + W_{P2} + W_i$

$$K_{11} = 1 - e^{-\frac{\Delta V_{12}}{g\, I_{sp}}}$$

ΔV_{12} = total one-way ΔV for the mission

$\Delta V_1 = \Delta V_{12} - \Delta V_2$ = first stage outbound ΔV

Solve for W_{P1}:

$$L (W_{P1})^2 + M W_{P1} + N = 0$$

where W_{P1} = total first stage propellant

$$L = (K_{10} - 1)^2$$

$$K_{10} = 1 - e^{-\frac{\Delta V_1}{g I_{sp}}}$$

$$M = W_i (K_{10})^2 + (A - 2W_i) K_{10} + B (K_{10} - 1)^2 - A$$

$$B = W_{P.L.} + W_{P2} + 2 W_i$$

$$N = -2 B W_i K_{10} + B W_i (K_{10})^2 + AW_i K_{10}$$

Then

$$K_1 = \frac{WP_1 - \dfrac{W_i \ K_{10}}{1 - K_{10}}}{W_{P1}}$$

where K_1 = percent W_{P1} used in the outbound leg.

The two-stage reusable case entails the return of both stages to the initial circular orbit. The return ΔV for each stage is assumed equal to the outbound ΔV experienced by the stage; and the returned payload is zero. Therefore, the first stage performance can be described by:

Outbound:

$$\frac{W_{P.L.} + W_{P2} + W_i}{W_{P.L.} + W_{P2} + 2W_i + W_{P1}} = 1 - \frac{W_{P1} + W_i}{K_1 W_{P1}} \left(1 - e^{-\frac{\Delta V_1}{gI_{sp}}} \right) \quad (1)$$

Return:

$$0 = 1 - \frac{(1-K_1)W_{P1} + W_i}{(1-K_1)W_{P1}} \left(1 - e^{-\frac{\Delta V_1}{gI_{sp}}} \right) \tag{2}$$

and the second stage, by:

Outbound:

$$\frac{W_{PL}}{W_{PL} + W_{P2} + W_i} = 1 - \frac{W_{P2} + W_i}{K_2 W_{P2}} \left(1 - e^{-\frac{\Delta V_2}{gI_{sp}}} \right) \tag{3}$$

Return:

$$0 = 1 - \frac{(1-K_2)W_{P2} + W_i}{(1-K_2)W_{P2}} \left(1 - e^{-\frac{\Delta V_1 + \Delta V_2}{gI_{sp}}} \right) \tag{4}$$

where

$W_{P.L.}$ = Payload

W_{PN} = Propellant in nth stage

W_i = Inert weight of one stage

ΔV_N = Total ΔV of nth stage

K_N = Fractional part of nth stage propellant expended in outbound mission phase (N = 1 or 2).

The second stage is assumed fully loaded with propellant. Using Equations (1) through (4) an equation for W_{P1} can be derived, as follows:

From (4)

$$K_1 = \frac{W_{P1} - \frac{W_i K_{10}}{1 - K_{10}}}{W_{P1}} \tag{5}$$

where,

$$K_{10} = 1 - e^{-\frac{\Delta V_1}{gI_{sp}}}$$

Substituting (4) in (3),

$$\frac{A}{B + W_{P1}} = 1 - \left(\frac{1}{K_1} + \frac{W_i}{K_1 W_{P1}} \right) K_{10} \tag{6}$$

where

$$A = W_{PL} + W_{P2} + W_i$$

$$B = W_{PL} + W_{P2} + 2W_i$$

Equation (6) can be rearranged to,

$$(K_{10} - 1)^2 W_{P1}^2 + \left[W_i K_{10}^2 + (A - 2W_i)K_{10} + B(K_{10} - 1)^2 - A \right] W_{P1}$$

$$+ (AW_i K_{10} + BW_i K_{10}^2 - 2BW_i K_{10}) = 0 \tag{7}$$

Equation (7) is a quadratic that can be solved for W_{PL}. The fractional part used for the outbound phase is obtained from (5). The fractional part of W_{P2} used for the outbound phase is obtained from (4).

It should also be noted that only one expendable stage (FW-4S, Agena, or Centaur) is listed for each mission in Table 3.3.1-1 and in each case, that stage is the least expensive one capable of providing the required delta-V.

Propellant requirements for Missions L-3 and L-4 are those corresponding to an outbound payload of 175,000 pounds and an inbound payload of 15,000 pounds under Mode 1 operating conditions. They are also based on a minimum energy transfer mission profile and were derived from References 3.3.1-1 and 3.3.1-2.

3.3.2 Program Orbital Propellant Requirements

Total payload propulsive stage propellant requirements for each of the five space program levels (A through E) and covering the 1979-1990 time period are summarized in Figures 3.3.2-1 through 3.3.2-4. These summaries reflect the

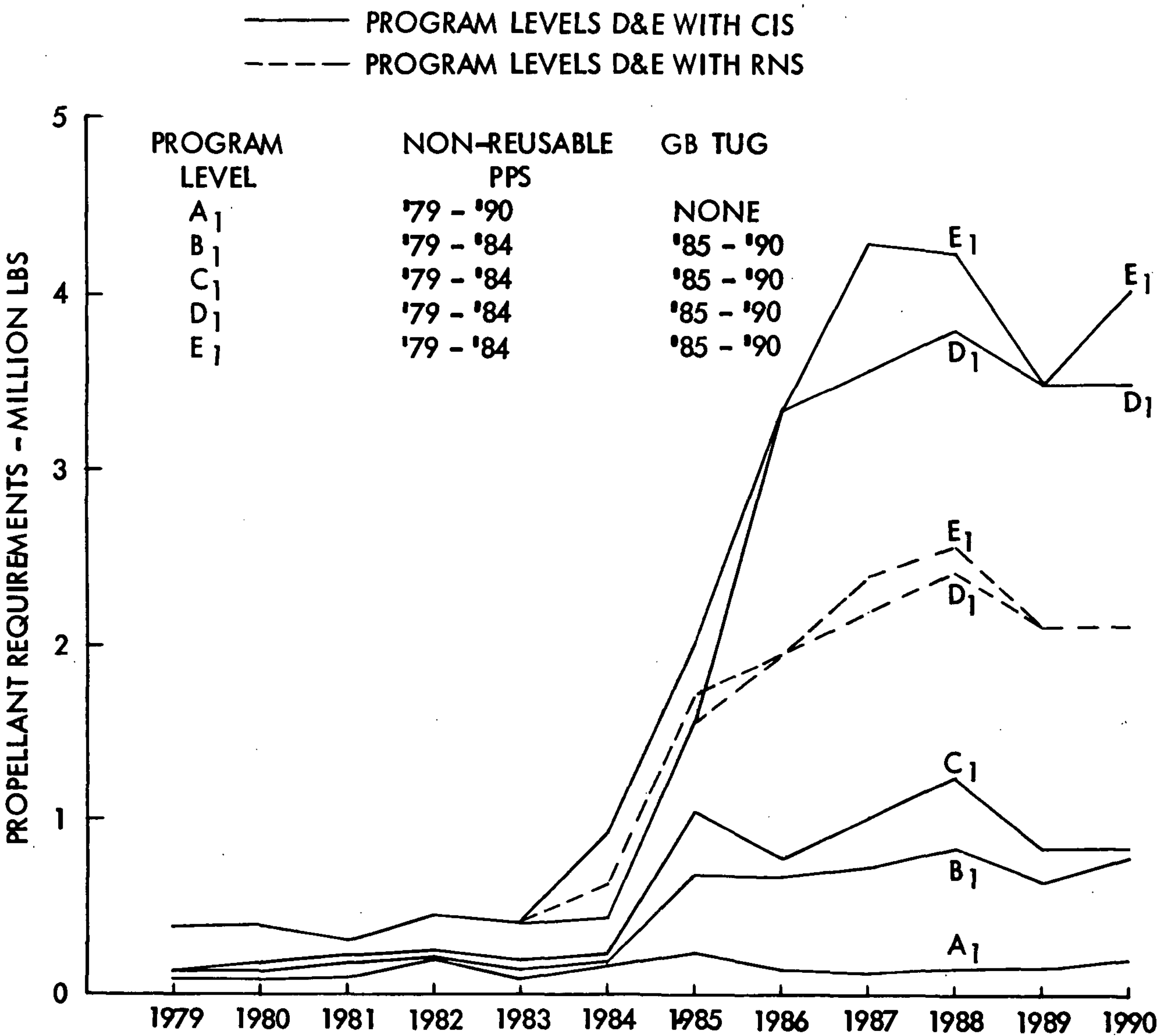

Figure 3.3.2-1 PPS Propellant Requirements GB Tug Available in 1985 for Programs D and E

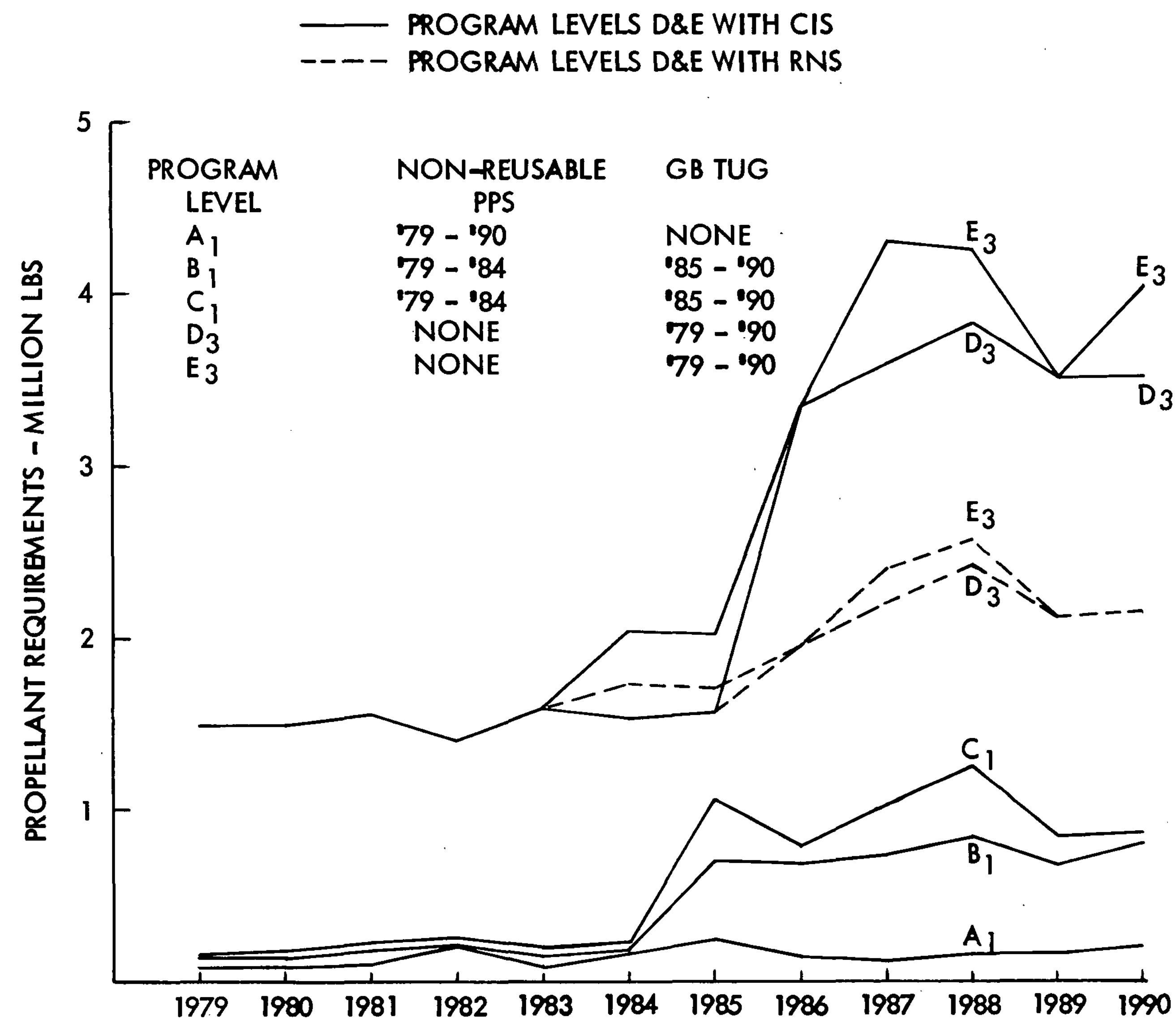

Figure 3.3.2-2 PPS Propellant Requirements GB Tug Available in 1979 for Programs D and E

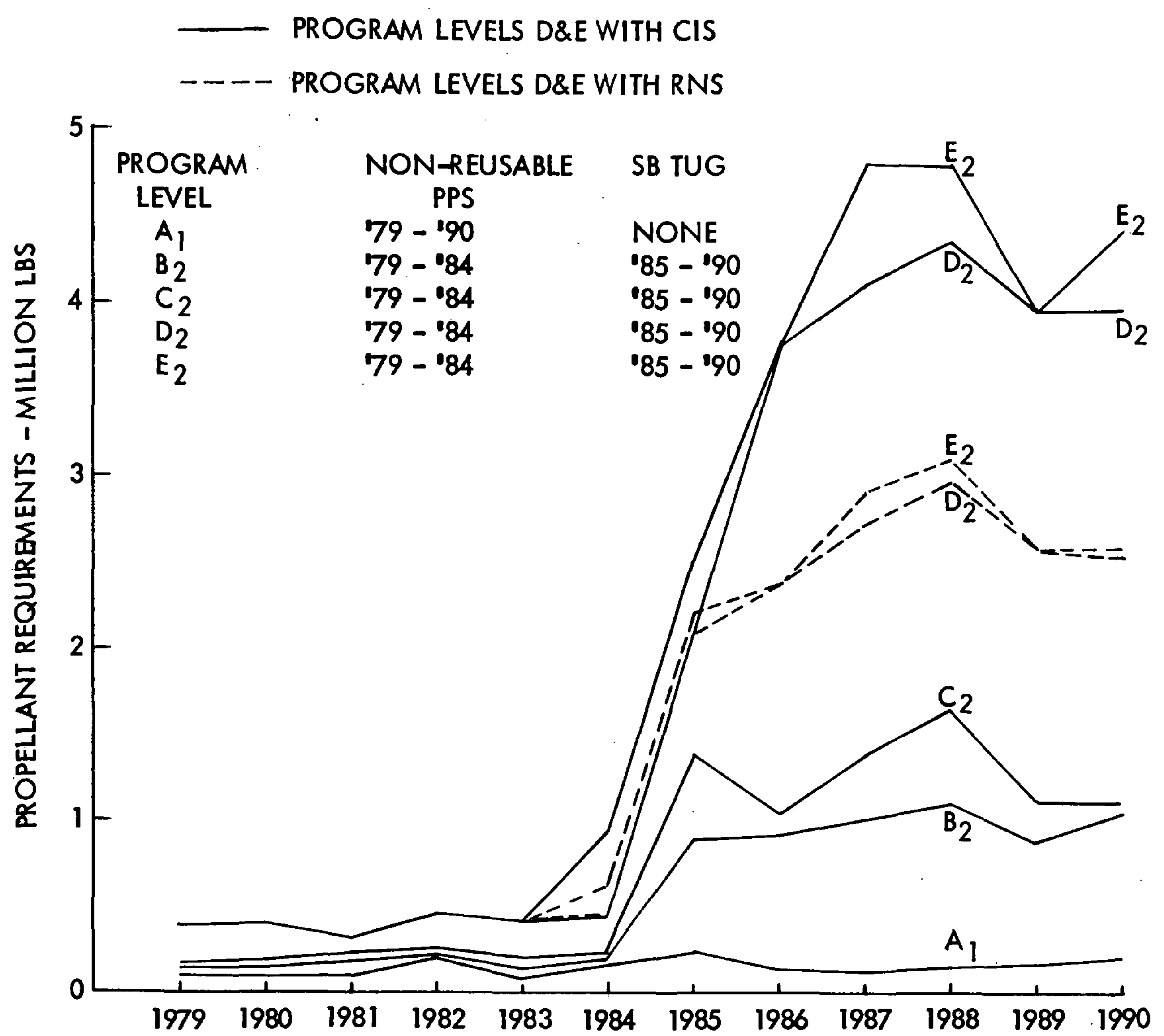

Figure 3.3.2-3 PPS Propellant Requirements SB Tug Available in 1985 for Programs D and E

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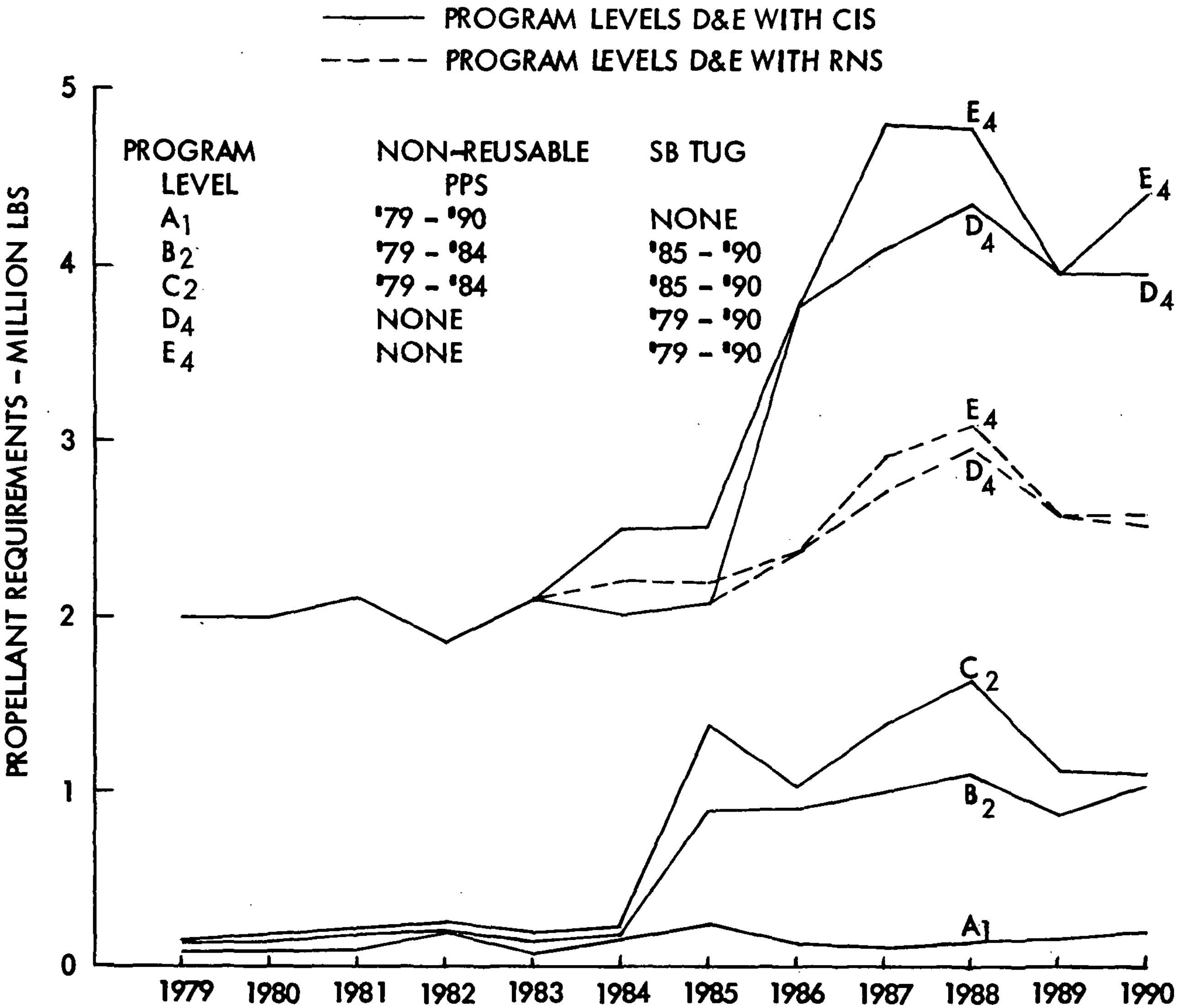

Figure 3.3.2-4 PPS Propellant Requirements SB Tug Available in 1979 for Programs D and E

ground-based and space-based tugs as alternate vehicles as well as the two tug availability dates (1979 and 1985) in Program Levels D and E. Propellant quantities shown in Figures 3.3.2-1 through 3.3.2-4 were established by addition of individual mission propellant requirements for each mission in each year and program level.

With reference to the Program Level Composition Guide of Table 3.2.3-1, Figure 3.3.2-1 shows the PPS propellant requirements for Program Levels A_1, B_1, C_1, D_1, and E_1; Figure 3.3.2-2 shows the requirements for Program Levels A_1, B_1, C_1, D_3, and E_3; Figure 3.3.2-3 shows the requirements for Program Levels A_1, B_2, C_2, D_2, and E_2; and Figure 3.3.2-4 shows the requirements for Program Levels A_1, B_2, C_2, D_4, and E_4.

The increase in propellant requirements for Program Levels B and C during the 1985-1990 time period, over the first six years of the program, reflects the introduction of the ground-based or space-based tug in 1985. The relatively large difference in propellant requirements between Program Levels C and D_3 (or D_4) during the 1979-1984 time period is the result of a larger number of placement missions in Program Level D (Missions 37, 78-2, 78-3, 78-4, L-1, and L-2) and the fact that either of the reusable tugs (Program Level D) requires more propellant to perform a given mission than the non-reusable vehicles (Program Level C). It should also be noted that the sharp rise in propellant requirements from 1985 to 1986 in Program Levels D and E results from the start of a lunar mission program (L-3 and L-4) utilizing the CIS or RNS as propulsive stages.

3.3.3 Orbital Altitude and Inclination Requirements

One planned category of information with regard to propellant requirements was concerned with the orbital altitude and inclination for payload placements. To aid in the development of this information, orbit placement and payload injection destinations have been plotted on an altitude inclination map (Figure 3.3.3-1) for all mission in the parametric space program. This map is helpful in identifying groups of missions by similar destinations and starting orbits for payload propulsive stages. These, in turn, provide basic conditions for later analysis of in-orbit propellant logistics concepts and operations.

The masked region in Figure 3.3.3-1 between 100 and about 425 nautical miles altitude and extending from 100 to slightly below 28.5 degrees inclination describes the nominal in-space operating regime of the shuttle orbiter. Major groups of missions performed by the shuttle without a payload propulsive stage include the space station, shuttle sorties, and a group of astronomy missions (large space telescope and observatories), the latter at 28.5 and 30 degrees inclination. The low magnetosphere explorer missions (Nos. 3B, 3C, and 3D) and the applications satellite missions (Nos. 30 and 32 at 90 degrees inclination) do require propulsive stages for payload placement since their orbits are highly elliptical. Only their perigees are shown on the map.

Major groupings of payload placement missions occur at synchronous equatorial orbit, at 28.5 and 30 degrees inclination, and at the polar region (90 to 100.7 degrees inclination). Since both the equatorial and 28.5 degree

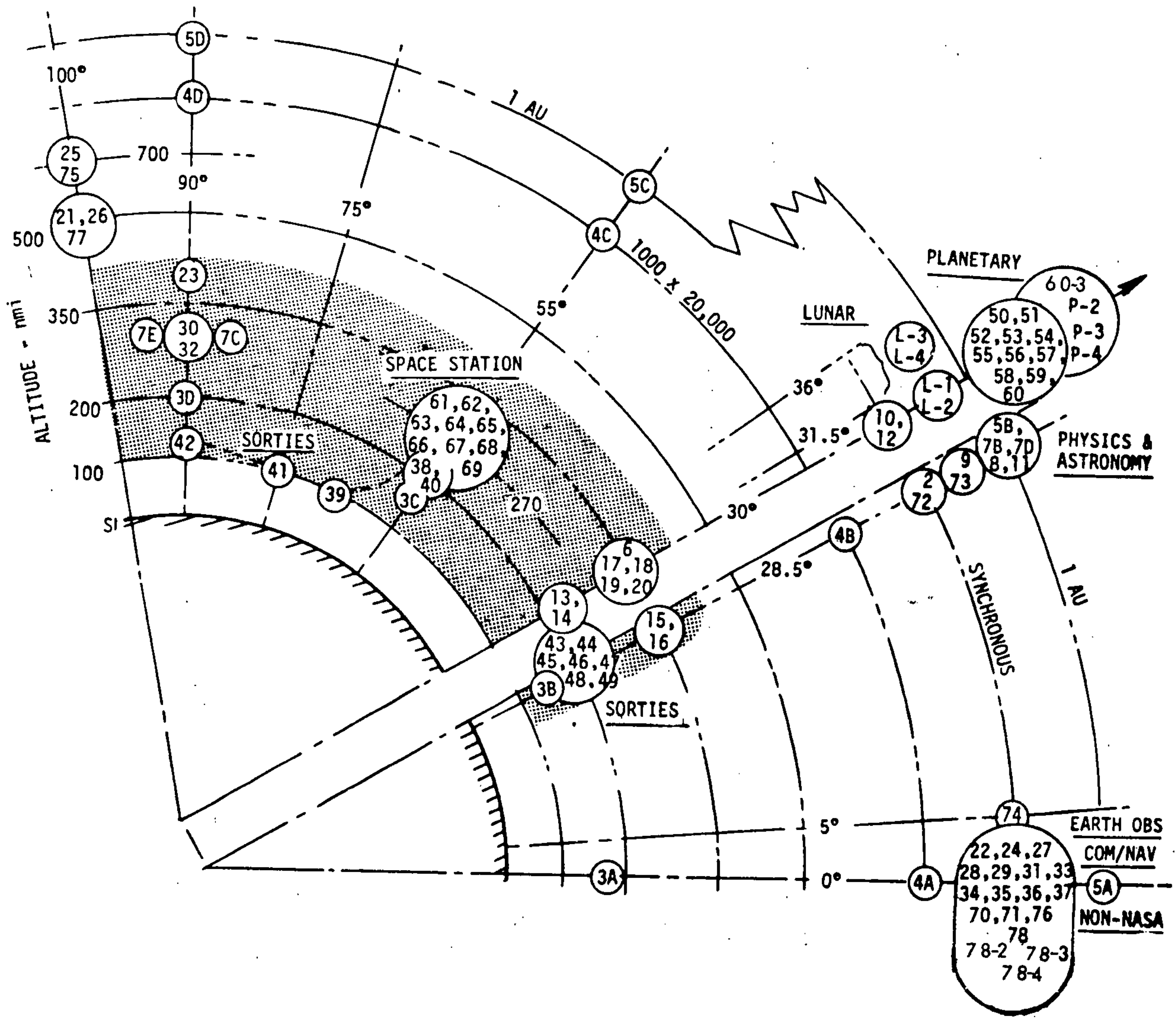

Figure 3.3.3-1 Orbital Altitude and Inclination Requirements

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Space Division
North American Rockwell

inclination placements involve propulsive stage starts from a 100 x 100 nautical mile orbit at 28.5 degrees, a meaningful grouping of location requirements is evident.

3.3.4 Shuttle Propellant Payload Requirements

The relative magnitude of the propellant payloads as compared with other shuttle payloads has been analyzed for all placements in Program Levels C and D. This analysis included not only the missions requiring a propulsive stage for payload placement, but also those missions which involve placement by shuttle alone, e.g., space station module delivery. The results of the analysis are presented in Figure 3.3.4-1 for the two vehicle options (ground-based versus space-based tug) applicable to Program Level C and the four options (ground-based versus space-based tug and tug availability date) applicable to Program Level D. These results indicate that propellants represent the major fraction of the total payload weight carried by the shuttle orbiter. This fraction varies from 52 percent of total shuttle payload weight in Program Level C with the ground-based tug in 1985-1990, to 78 percent in Program Level D with the space-based tug in 1979-1990.

The bottom portion of each bar in Figure 3.3.4-1 represents the total weight of propellants (both cryogenic and hypergolic) which is required for payload placement missions and is carried either in a propulsive stage or a propellant tank within the shuttle cargo bay as applicable; the middle portion of each bar represents the total weight of the empty propulsive stages and/or propellant tanks involved in the transport of the propellants; and the upper portion of each bar represents the total weight of all scientific payloads in each program level and option. The portion of propellant required for the CIS (10.75 million pounds) is also indicated for Program Level D.

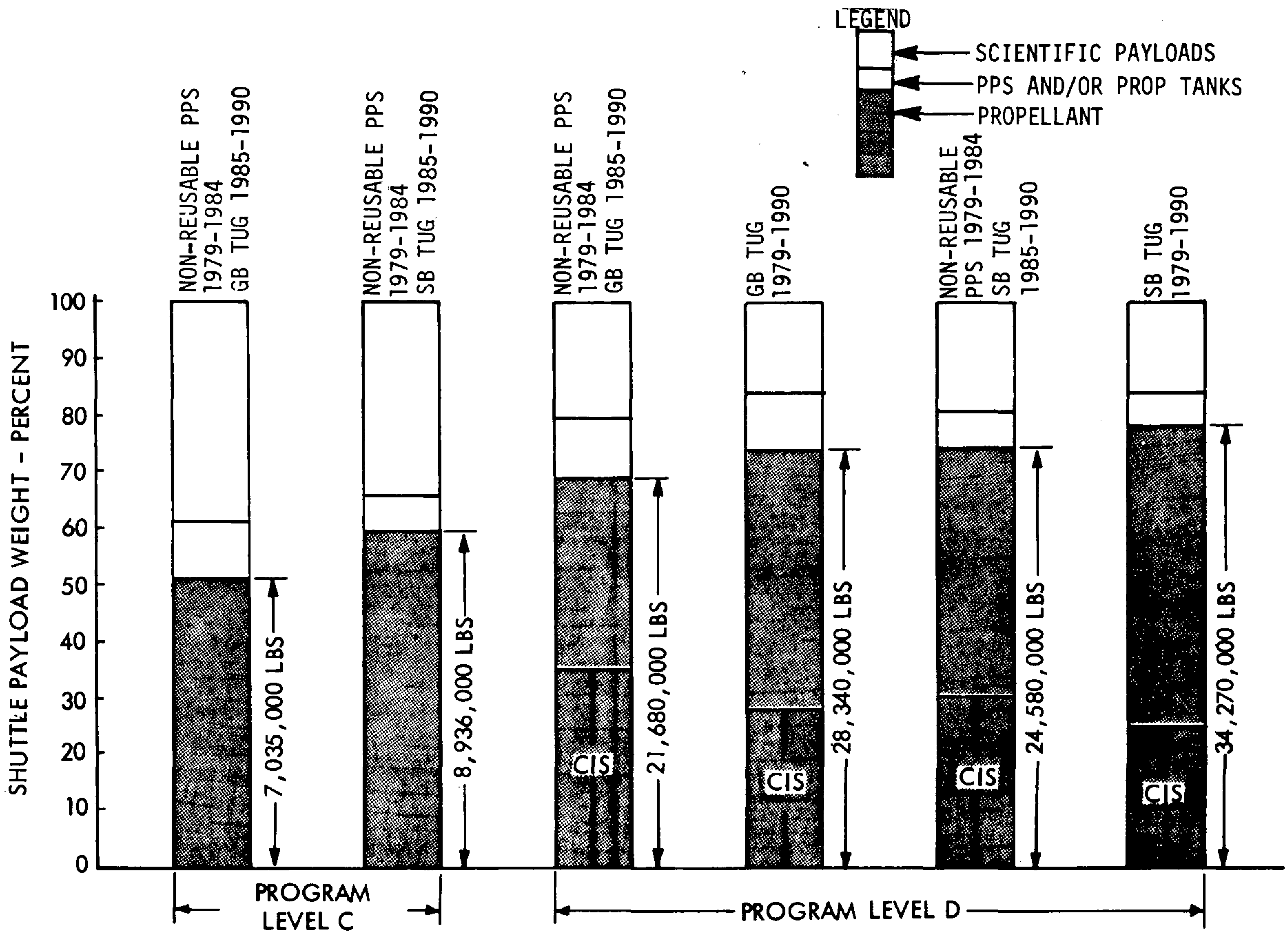


Figure 3.3.4-1 Shuttle Propellant Payload Requirements

3.4 REFERENCES

3.1-1 "The Next Decade in Space," a Report of the Space Science and Technology Panel of the President's Science Advisory Committee, March 1970

3.1-2 "Modular Space Station Phase B Extension, Preliminary System Design," North American Rockwell, Space Division SD71-217-1, January 1972

3.1-3 "Orbiting Lunar Station (OLS) Phase A Feasibility and Definition Study," North American Rockwell, Space Division SD71-207, April 1971

3.1-4 "Lunar Base Synthesis Study, Final Report," North American Rockwell, Space Division SD71-477, 15 May 1971

3.3.1-1 "Nuclear Flight System Definition Study," Phase III Final Report, North American Rockwell, Space Division Report SD71-466-2, April 1971 (Contract NAS8-24975)

3.3.1-2 "S-II Stage Interorbital Shuttle Capability Analysis," North American Rockwell, Space Division Report SD71-245-3, April 24, 1971, (Change Order 2021 to Contract NAS7-200)

4.0 PROPELLANT LOGISTICS CONCEPTS DEVELOPMENT

Space traffic models and time-phased user propellant requirements were established in Section 3.0. Candidate propellant logistic concepts for providing those propellants, time-phased, in space are developed in this section.

The elements of the propellant logistic system are the earth to earth-orbit transport vehicle (shuttle orbiter or shuttle booster/expendable second stage (ESS)); the propellant logistic tank (propellant module) which carries the propellants during transport and provides for their transfer in orbit; and orbital storage (large depot, mini-depot, storage in the user vehicle, storage in a second user vehicle); or no orbital storage.

The material developed in Section 3.0 leads to the identification of the three distinct operational variations illustrated in Figure 4.0-1 for which concepts are developed.

a. An earth-based concept incorporates a payload propulsive stage (PPS) which is launched from earth in the shuttle cargo bay along with its payload and sufficient propellants to carry the payload to its placement altitude from low earth altitude and return to rendezvous with the shuttle in low earth orbit.

b. A space-based payload propulsive stage creates a much different operational concept and offers a number of options not available in a ground-based program. In this concept the payload plus the necessary propellants are brought from the earth surface to low earth orbit in a shuttle cargo bay. The propellants and payload are transferred to the PPS, the PPS places the payload into its proper orbit and returns to low orbit to await the next shuttle rendezvous. The shuttle in the meantime may stand by until the PPS returns to load remaining propellants into the PPS and then return to earth with the empty propellant tank, or return to earth immediately.

c. The addition of separate in-orbit storage capability to the space-based concept provides the opportunity to maximize shuttle utilization and flexibility by providing for storage of excess propellants, or propellants required for PPS missions which exceed the capacity of a single shuttle flight, for later use by the space-based PPS. This leads to a yet different and more complex analysis.

The expendable second stage (ESS) for use with shuttle booster is an alternate earth to earth-orbit delivery system which has been evaluated in the study in conjunction with space-based programs, for cost comparison with shuttle orbiter delivery. Not shown is the use of a space-based tug to transport the propellant module from the shuttle orbiter at 100 n mi to a higher user altitude which was also developed for cost comparison with shuttle orbiter delivery.

A total of seven concept variations were developed which will, in Section 5.0, be applied to the thirteen implementations of the five levels of space program activity, developed in Section 3.0, and subjected to a cost effectiveness analysis. These seven concepts are summarized in Figure 4.3-1.

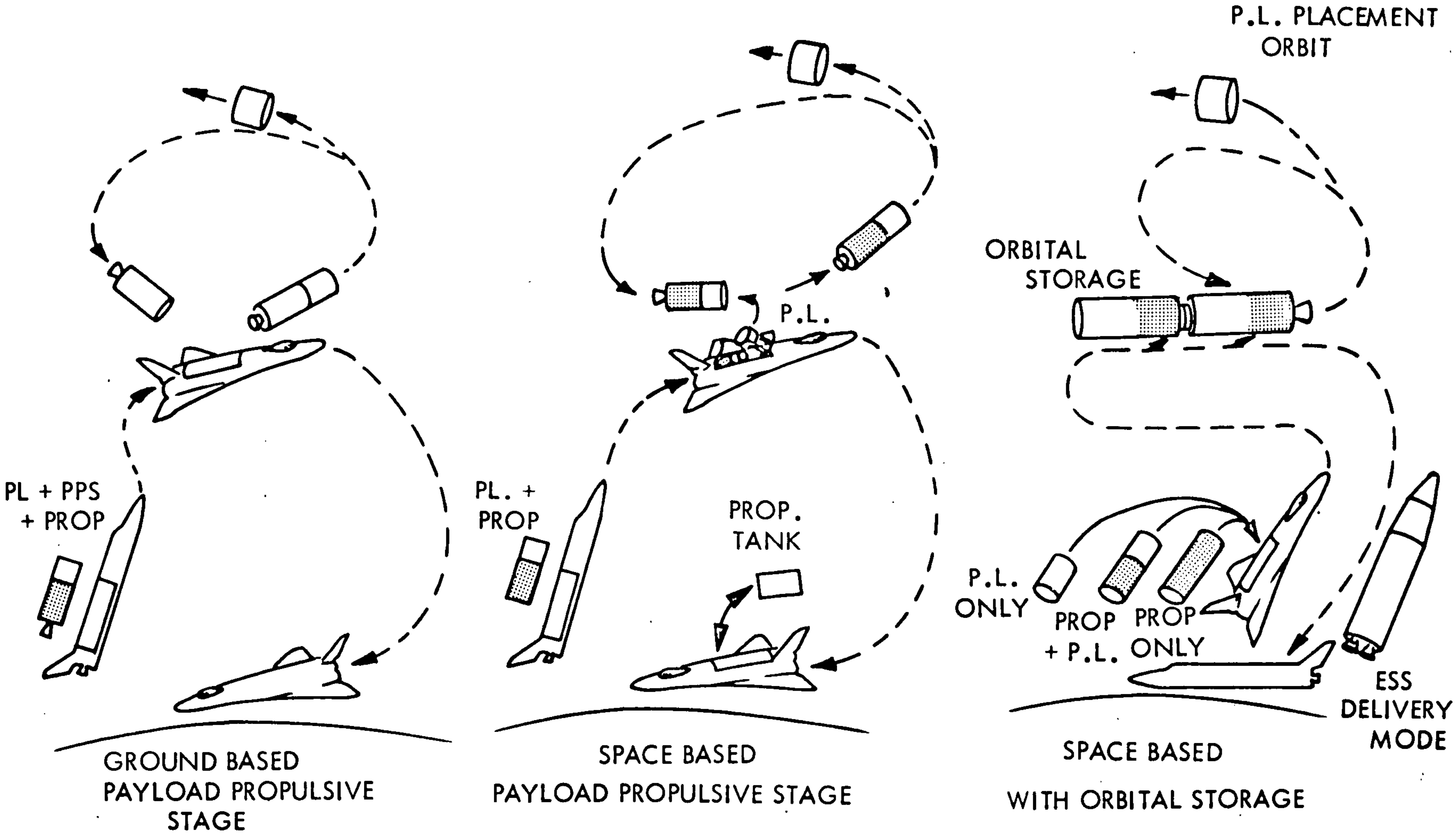


Figure 4.0-1 Propellant Logistic Operational Variations

4.1 EARTH-TO-EARTH ORBIT TRANSPORT MODES

The delivery of payload to space considered for this study involved two basic methods. These are (1) the use of the shuttle orbiter cargo bay, and (2) the use of the shuttle booster with an expendable second stage (ESS). The characteristics and application of these transport modes are described below.

4.1.1 Shuttle Orbiter Cargo Bay

The basic transport vehicle considered for carrying payloads from earth to low earth orbit is the space shuttle. The characteristics of the shuttle orbiter are shown in Figure 4.1.1-1. The payload capability is 65,000 pounds delivered to 100 nautical miles at 28.5 degrees inclination within a cargo bay sized for payloads up to 15 feet in diameter and 60 feet long. The capacity to 100 nautical miles at 90 degrees inclination is 40,000 pounds.

The shuttle cargo bay is considered to be capable of handling a range and combination of payloads including:

a. Scientific payload only

b. Scientific payload mounted on a payload propulsive stage (PPS), including FW-4S, Agena, Centaur D1-T, and ground-based tug

c. Scientific payload + propellant logistics module

d. Propellant logistics module only

e. Ground-based tug or space-based tug only

Figure 4.1.1-2 shows the center of gravity limits for cargo in the shuttle orbiter and Figure 4.1.1-3 shows the range of movements for the shuttle manipulator arms.

4.1.2 Shuttle Booster with ESS

A secondary technique of delivering propellant to low earth orbit considered in the study was the use of the shuttle booster with an expendable second stage, the propellant logistics tank being the ESS payload. The characteristics of this method of propellant delivery are illustrated in Figures 4.1.2-1 and 4.1.2-2. This mode of propellant delivery is suitable for use with a large orbiting propellant depot or for fueling a CIS/RNS. It is not suitable for direct feeding of a space-based tug due to the excess capacity of the delivery mode.

4.2 ORBITAL STORAGE CONCEPTS

Orbital storage of propellants is a potential requirement for an in-space propellant logistics system. Large depots which contain sufficient propellants to completely refuel a CIS or RNS have been studied in detail in previous studies (i.e., S-II Orbital Propellant Storage System Study, Reference 4.2-1). Consideration must be given also to the possibility of small orbital storage

ORBITER

INERT WEIGHT (WITHOUT CARGO)	193,500 LB(87,770 Kg)
PROPELLANT(OMS & ACS)	18,100 LB(8,210 Kg)
LOSSES & RESERVES)	4,800 LB(2,177 Kg)

DROP TANK

INERT WEIGHT	62,000 LB(28,123 Kg)
PROPELLANT(USABLE)	933,700 LB(423,519 Kg)
(RESERVES & LOSSES)	12,600 LB(5,715 Kg)

PAYLOAD CAPABILITY

BAY SIZE 15' DIA x 60'(4.57 x 18.3 M)

TO 100 nmi AT 28.5°	65,000 LB (29,500 Kg)
TO 100 nmi AT 90°	40,000 LB (18,100 Kg)

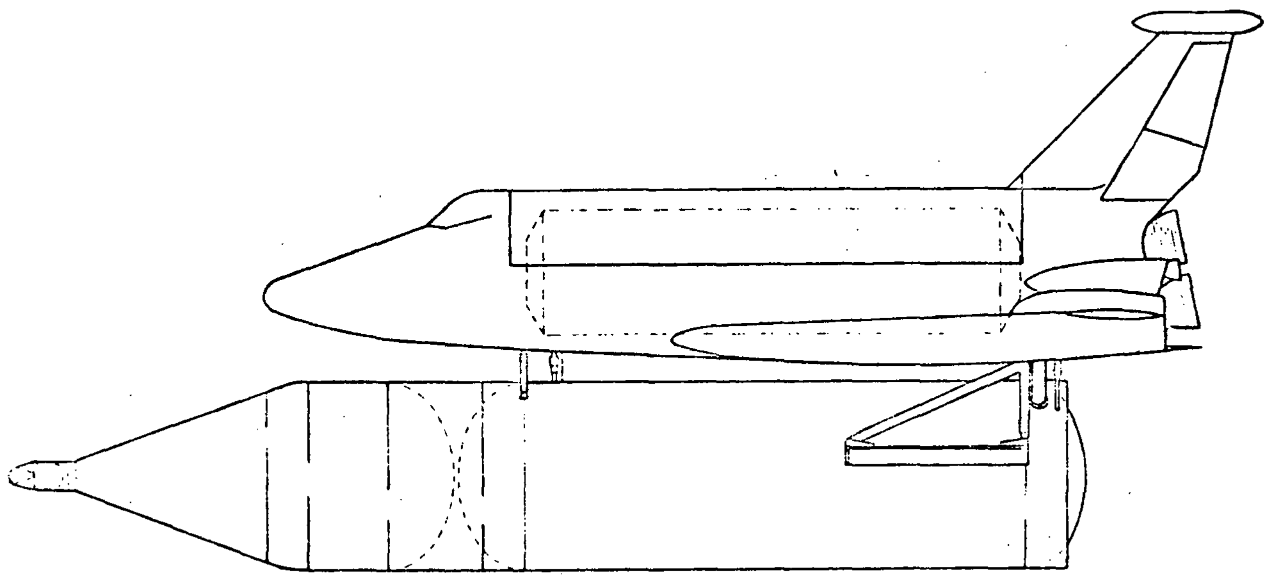
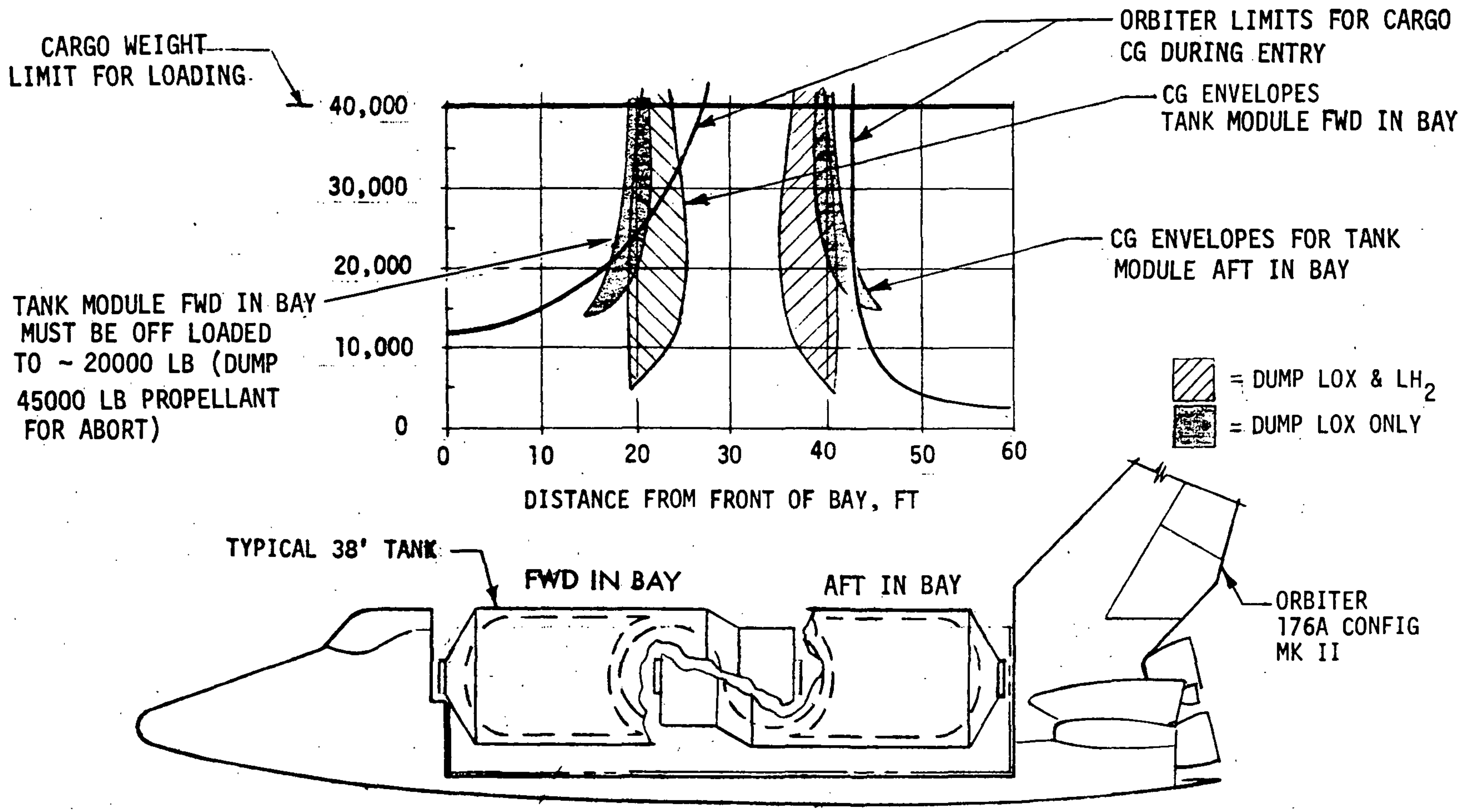


Figure 4.1.1-1 Space Shuttle (Drop Tank) Orbiter Pressure Fed Configuration



- **ABORT DUMP REQUIREMENT LESS SEVERE WITH LOGISTIC TANK AFT**

Figure 4.1.1-2 CG Location In Orbiter

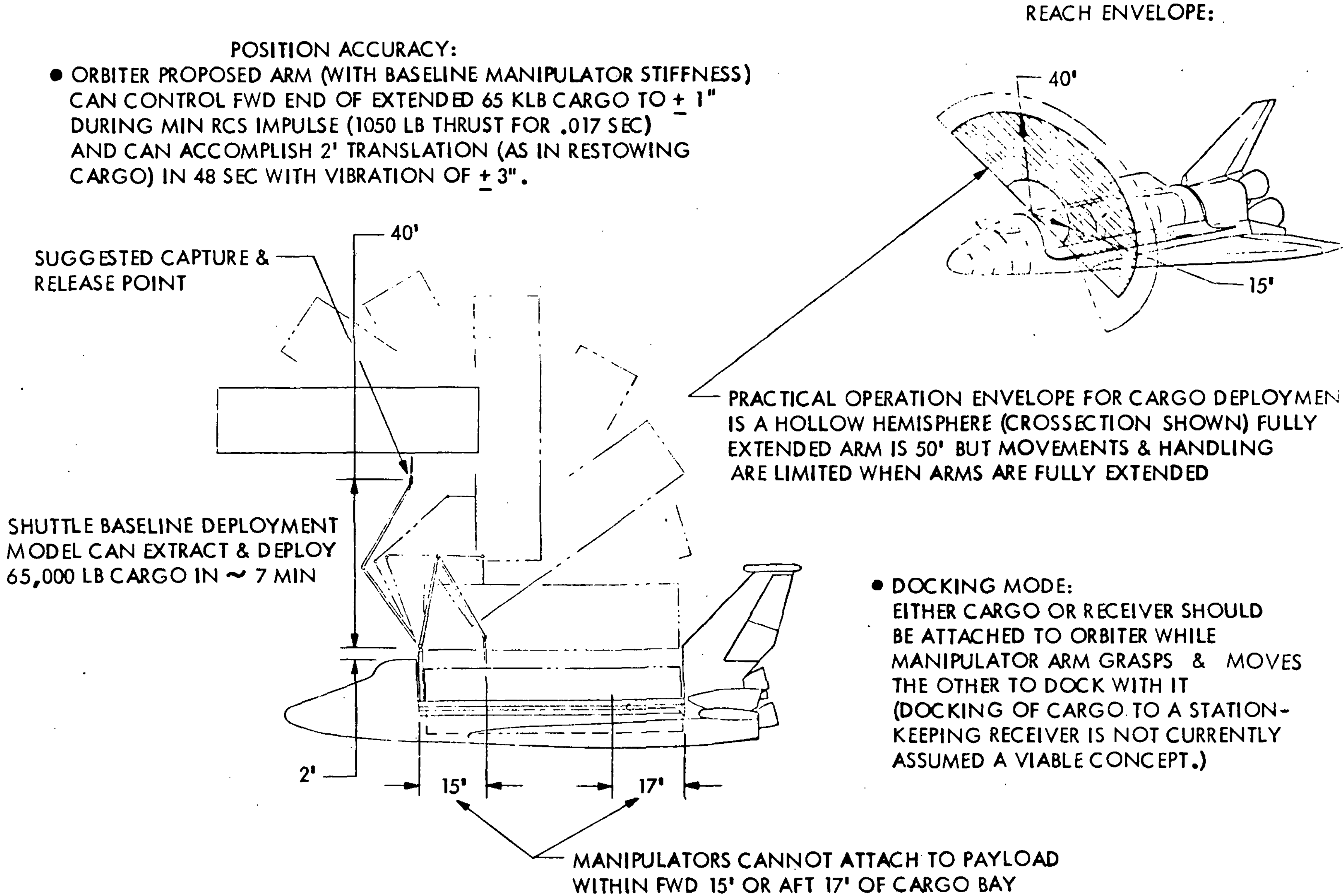
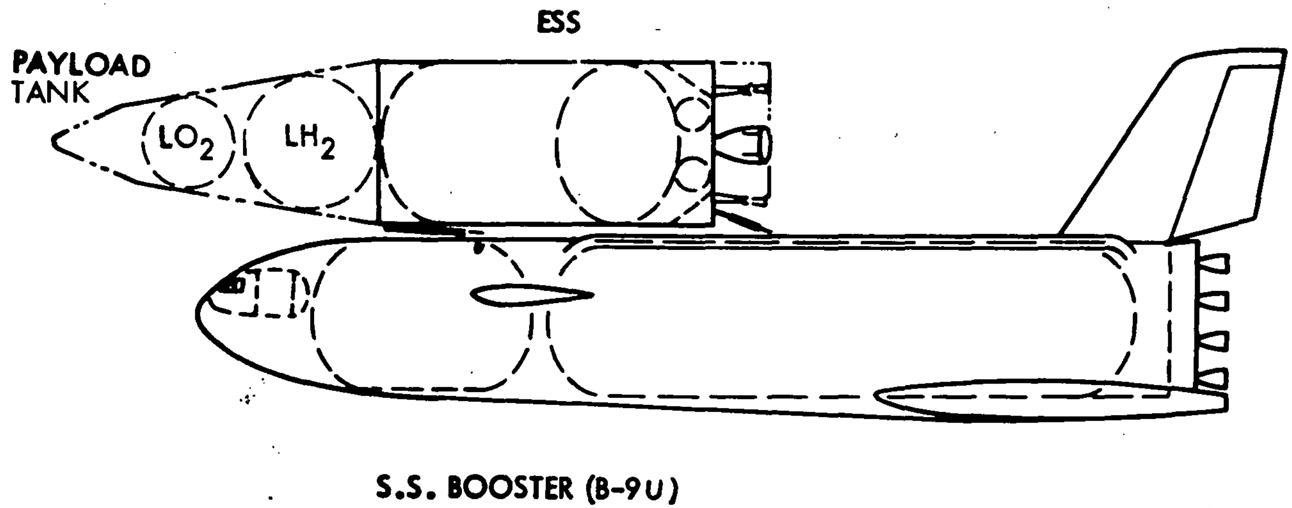


Figure 4.1.1-3 Orbiter Manipulator Arm Capabilities

SD72-SA-0053-2



BOOSTER:

INERT WT	655,000 LB
PROPELLANT (ASCENT)	3,382,000 LB
THRUST (SL)	6,600,000 LB

ESS:

INERT WT	103,000 LB
PROPELLANT (ASCENT)	677,000 LB
THRUST (VAC)	1,264,000 LB

PAYLOAD CAPABILITY

TO 100 nmi	206,000 LB
TO 180 nmi	200,000 LB

Figure 4.1.2-1 Shuttle Booster & Expendable Second Stage (ESS)

WEIGHT: (EMPTY) 15,500 LB (7,030 KG)

CAPACITY

LH_2	28,400 LB (12,900 KG)
	6,530 CU FT (185 CU M)
LO_2	150,000 LB (68,500 KG)
	2,120 CU FT (60 CU M)

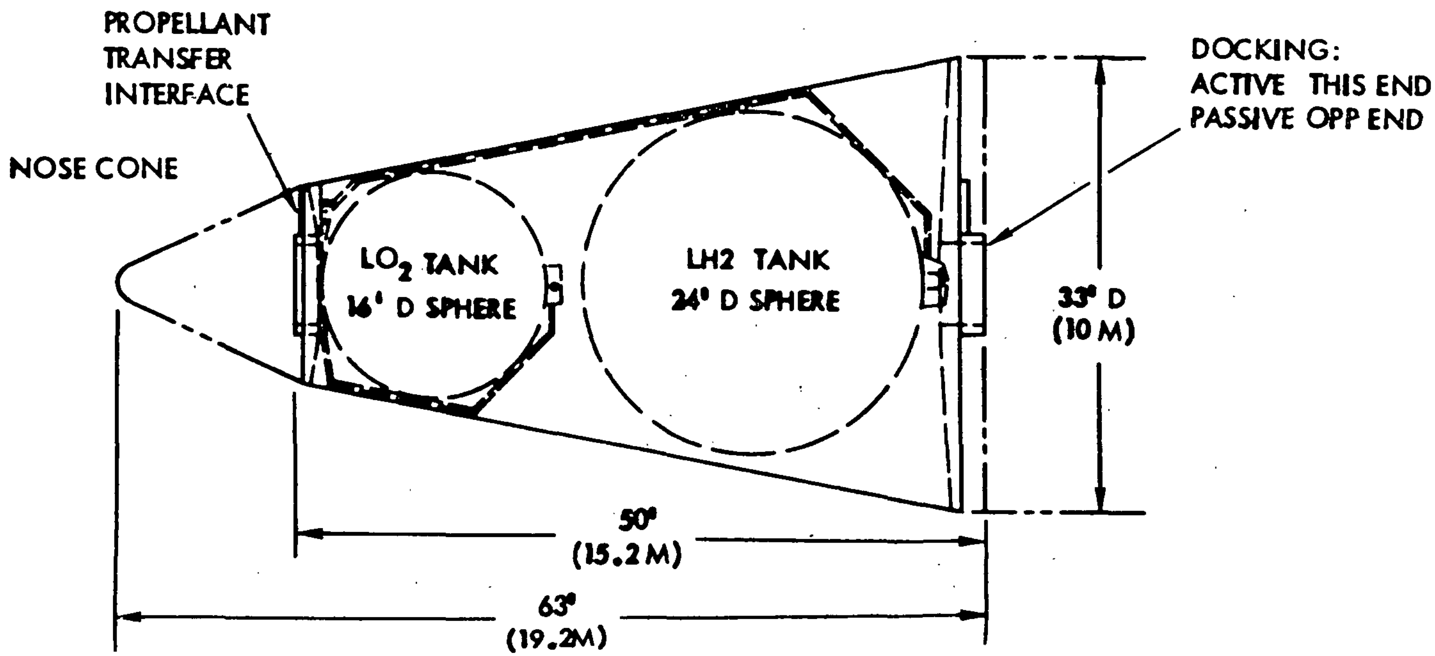


Figure 4.1.2-2 ESS Propellant Logistics Tank

facilities (mini-depot) suitable for refueling a space-based tug, and to the possibility of storage within the user vehicle itself (self storage). A particular objective of this overall systems/operations analysis is to establish whether a separate storage depot is required. Concepts are developed which include the three storage concepts mentioned for later cost comparison with those concepts in which no orbital storage is provided.

One of the considerations in evaluating the desirability of orbital storage is the operational flexibility which it provides. That is, it precludes, or relieves the requirement for exact synchronizing of the earth-to-earth orbit logistic flights with user vehicle flights. Depot weight is not the serious consideration that it is on supplier and user vehicles. They can, therefore, (1) be of unusual configuratin having counterweights, booms, multiple tanks, etc., to accommodate center of gravity excursions associated with rotational acceleration for propellant settling, and (2) contain the systems and controls required for propellant transfer which, in some cases, would otherwise be an added weight increment on the supplier or user vehicle.

4.2.1 Large Depot

The concept of a large orbital propellant depot was developed by the OPSS study and that data is used in this study wherever a large depot is referred to. The characteristics of such a depot are shown in Figure 4.2.1-1. A more detailed description may be found in Reference 4.2-1.

4.2.2 Mini-Depot

The nature and sequence of a large number of the missions using a space-based tug for placement of the scientific payload indicated that a depot having the capacity about equal to that of the tug could satisfy the storage requirements. Therefore, a concept of a mini-depot was developed for consideration in propellant logistics operations.

The mini-depot serves the same function as the large depot in that it is a reservoir for in-space propellant, but the size is small, thus reducing development and production costs. Four mini-depot concepts were developed: two with modular delivery where the logistic tank remains in orbit to store propellant, and two with permanent depot tankage. Both categories have a separate configuration for propellant settling mode of either linear or rotational acceleration. These concepts are summarized in Figure 4.2.2-1. Detailed description of these mini-depot concepts are presented in Volume III, Section 5.0.

4.2.3 Self Storage

Another concept of orbital propellant storage is that of using the receiver vehicle as a storage facility between missions. This is particularly applicable to space-based tug operation. No separate storage facility is required for this concept, although within limits the function of a separate depot is duplicated.

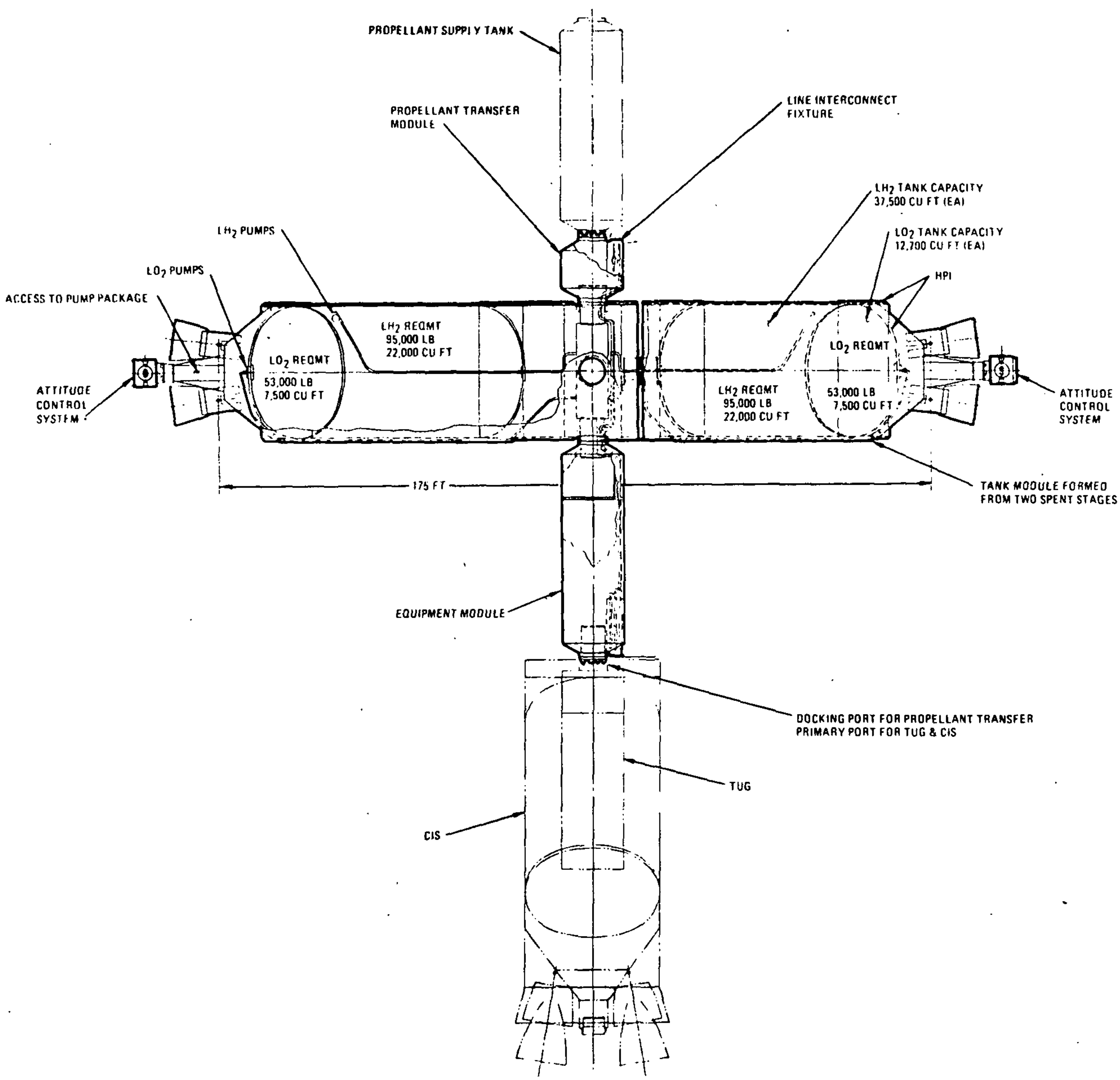
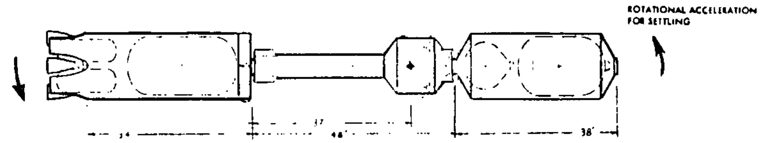


Figure 4.2.1-1 Large Orbital Propellant Depot

1A MODULAR, ROTATIONAL MINI-DEPOT

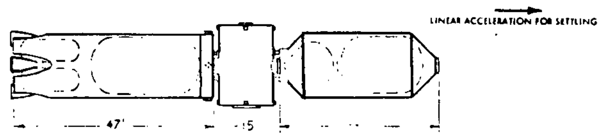


ELEMENTS: EQUIP MODULE & LOGISTICS/STORAGE TANK

FEATURES: ROTATIONAL SETTLING REDUCES PROP USE
EQUIP MOD REQS SEPARATE LAUNCH

OPERATION: (BOTH)
ORBITER DELIVERS PROPELLANT TANK
TANK BECOMES PART OF DEPOT UNTIL EMPTY
EQUIP MOD PROVIDES TRANS & SETTLING CAPABILITY
PROP TRANS FLUID TO TUG FROM L/S TANK
ORBITER RETURNS TANK WHEN EMPTY (NEXT TRIP)

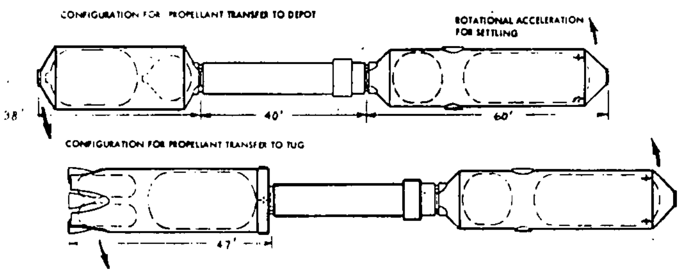
1B MODULAR, LINEAR MINI-DEPOT



ELEMENTS: EQUIP MODULE & LOGISTICS/STORAGE TANK

FEATURES: EQUIP MOD & TANK CAN SHARE LAUNCH
SHORTER TRANS LINES; LESS BOILOFF

2A PERMANENT TANKAGE, ROTATIONAL MINI-DEPOT

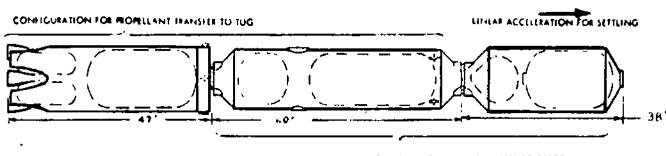


ELEMENTS: DEPOT MODULE, BOOM & LOGISTICS TANK

FEATURES: ROTATIONAL SETTLING REDUCES PROP USE
PERMANENT TANK REDUCES BOILOFF
BOOM REQS SEPARATE LAUNCH

OPERATION: (BOTH)
ORBITER DELIVERS PROPELLANT TANK
TANK IS ATTACHED (TUG DETACHED) & PROP IS TRANSFERRED (FLUID) TO DEPOT
ORBITER RETURNS EMPTY TANK TO GROUND
TUG DOCKS RECEIVES PROP (FLUID TRANS) FROM DEPOT TANKS
DEPOT PROVIDES TRANS & SETTLING CAPABILITY

2B PERMANENT TANKAGE, LINEAR MINI-DEPOT



ELEMENTS: DEPOT MODULE & LOGISTICS TANK

FEATURES: SINGLE LAUNCH FOR DEPOT
SHORTER TRANS LINES; LESS BOILOFF

Figure 4.2.2-1 Mini-Depot Concepts Comparison

4.3 PROPELLANT DELIVERY OPERATIONS

The basic elements of the propellant logistics system required to service space-based tug and/or CIS/RNS operations have been defined. The operational concepts of using these elements are described in this section.

The problem of refueling the space-based tug and CIS/RNS are sufficiently different to be analyzed separately. The CIS/RNS fueling operation consists of a number of shuttle flights each carrying a full load of propellants to orbit and subsequent transfer of the propellant to the CIS/RNS. The operations would be repeated until the CIS/RNS is completely fueled. The delivery could be direct, that is, the shuttle carrying the propellant to the parking orbit of the CIS/RNS. The propellant delivery by the shuttle could be to 100 nautical miles with a tug carrying the propellant logistics module to the CIS/RNS parking orbit. This approach requires extra operations and should be avoided if possible. It is analyzed in more detail in Section 7.0.

Careful attention was given to the selection of the propellant logistics operational concepts for tug support. These are summarized in Figure 4.3-1. The ground-based concepts using the space shuttle for delivery of a PPS and attached scientific payload to 100 n mi circular orbit and subsequent deployment are reasonably straightforward. Figure 4.3-2 illustrates the operational concept. The data for cost comparisons are based on the number of shuttle fights required to carry the PPS plus scientific payload to orbit. Propellant is loaded into the PPS on the ground and no orbital propellant storage or transfer is required. However, the operations on space-based tug are more complicated and offer many viable operating concepts.

A total of five propellant logistics operational concepts were selected for space-based tug analysis. The objective was to provide a wide range of operating techniques that would reflect cost differences, and that would represent reasonable operating modes. The concepts reflect operating the shuttle carrying partial and full payloads on each flight; operating with and without orbital propellant storage; and using different orbital storage techniques. Defining five operational concepts for space-based tug operations resulted in modifying the program composition guide such that a total of 37 separate program implementations were outlined for analysis. This gave considerable parametric depth to the study providing not only a range of program activity, but also a simultaneous range of program operational concepts. The range of analysis is summarized in Figure 4.3-3.

The five space-based tug operating concepts are summarized below with the rationale for selection.

Concept 1. Space-Based Tug - No Storage - Partial Shuttle Payload (Figure 4.3-4). This concept utilizes a tug maintained in orbit with enough propellant to provide for orbital maintenance, boiloff losses, electrical power, stabilization for docking and other requirements. A shuttle is launched with tug propellant and a payload for the satellite placement mission. The propellant for the placement mission is transferred to the tug followed by the payload. The tug places

SHUTTLE DELIVERY TO 100 nmi						
		REUSABLE SPACE BASED TUG				
NON REUSABLE FW-4S AGENA CENTAUR	REUSABLE GROUND BASED TUG	CONCEPT 1 NO STORAGE	CONCEPT 2 SELF ACCUMULATION	CONCEPT 3 TWO TUGS	CONCEPT 4 DEPOT	CONCEPT 5 DEPOT
PAYLOAD FULLY LOADED PPS	PAYLOAD FULLY LOADED PPS	PAYLOAD + TANK CARRYING ONLY WHAT IS NEEDED FOR SPECIFIC MISSION SPECIAL PROPELLANT FLIGHTS WHEN NEEDED	PAYLOAD + TANK CARRYING FULL LOAD SPECIAL PROPELLANT FLIGHTS WHEN NEEDED	PAYLOAD + TANK CARRYING FULL LOAD SPECIAL PROPELLANT FLIGHTS WHEN NEEDED	PAYLOAD + TANK CARRYING FULL LOAD SPECIAL PROPELLANT FLIGHTS WHEN NEEDED	PAYLOAD + PROPELLANT IN SEPARATE SHUTTLE FLIGHTS SPECIAL PROPELLANT FLIGHTS WHEN NEEDED
SHUTTLE RETURN						
EMPTY	GB TUG	EMPTY TANK	EMPTY TANK	EMPTY TANK	EMPTY TANK	EMPTY TANK
SEPARATE EQUIPMENT NEEDED						
NONE	NONE	TANK + TRANSFER EQUIP	TANK + TRANSFER EQUIP	TANK + TRANSFER EQUIP	TANK + DEPOT + TRANSFER EQUIP	TANK + DEPOT + TRANSFER EQUIP
NOTE: TANK = PROPELLANT LOGISTIC MODULE						

Figure 4.3-1 Propellant Logistics Concepts Summary

Space Division
North American Rockwell

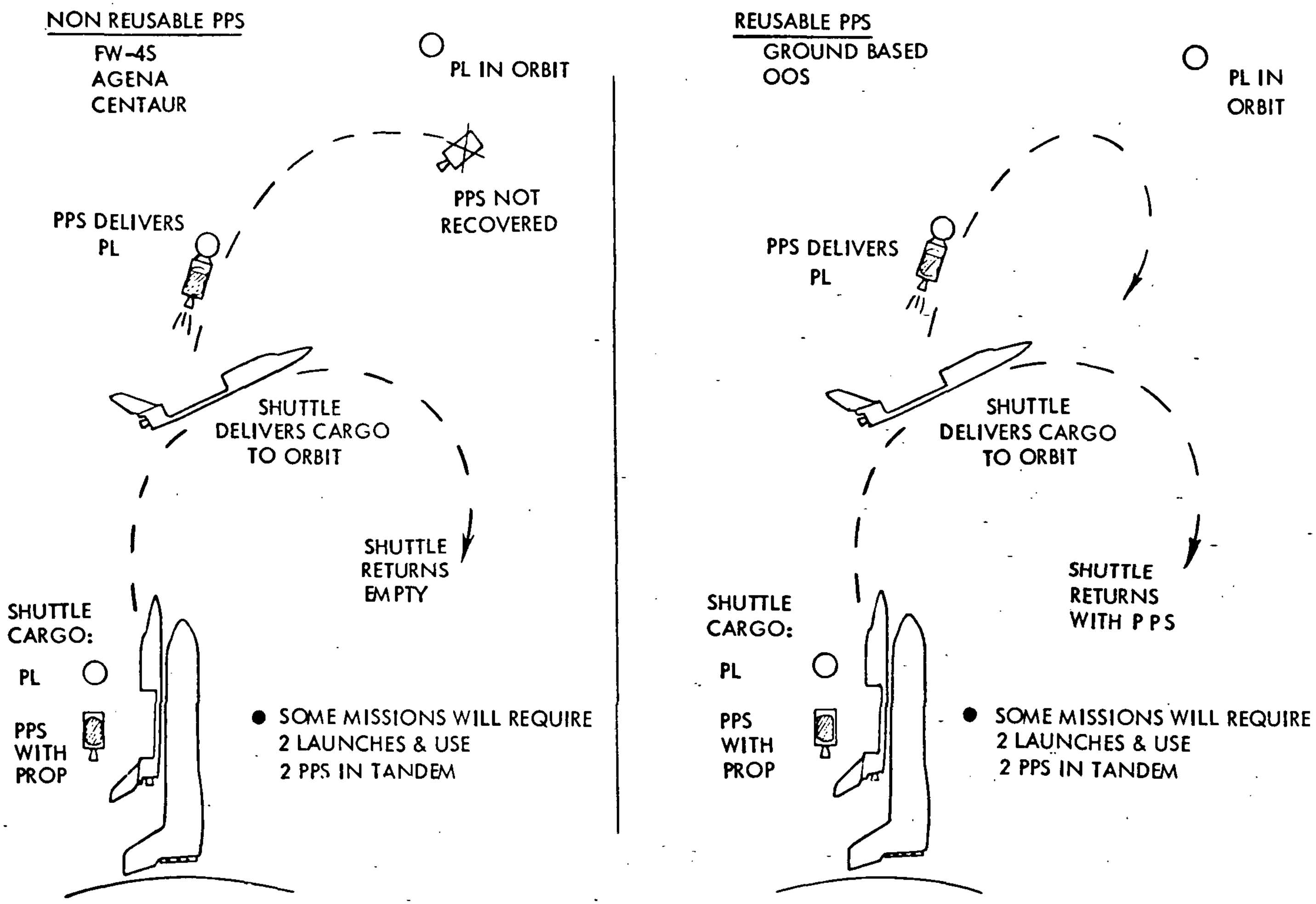


Figure 4.3-2 Operational Concept for Payload Delivery With Ground Based Payload Propulsive Stage

PROGRAM LEVEL (WITH DESIGNATOR)	PAYLOAD PROPULSIVE STAGE		OPERATION CONCEPTS
	1979-1984	1985-1990	
A_1	EXPENDABLES	EXPENDABLES	1
B_1	EXPENDABLES	G.B. TUG	1
B_2	EXPENDABLES	S.B. TUG	1, 2, 3, 4, 5
C_1	EXPENDABLES	G.B. TUG	1
C_2	EXPENDABLES	S.B. TUG	1, 2, 3, 4, 5
D_1	EXPENDABLES	G.B. TUG	1
D_2	EXPENDABLES	S.B. TUG	1, 2, 3, 4, 5
D_3	G.B.TUG	G.B. TUG	1
D_4	S.B. TUG	S.B. TUG	1, 2, 3, 4, 5
E_1	EXPENDABLES	G.B. TUG	1
E_2	EXPENDABLES	S.B. TUG	1, 2, 3, 4, 5
E_3	G. B. TUG	G. B. TUG	1
E_4	S. B. TUG	S. B.TUG	1, 2, 3, 4, 5

NOTE: EXPENDABLES REFERS TO USE OF FW-4S, AGENA, CENTAUR D1-T

Figure 4.3-3 Program Composition Guide With Operational Concepts

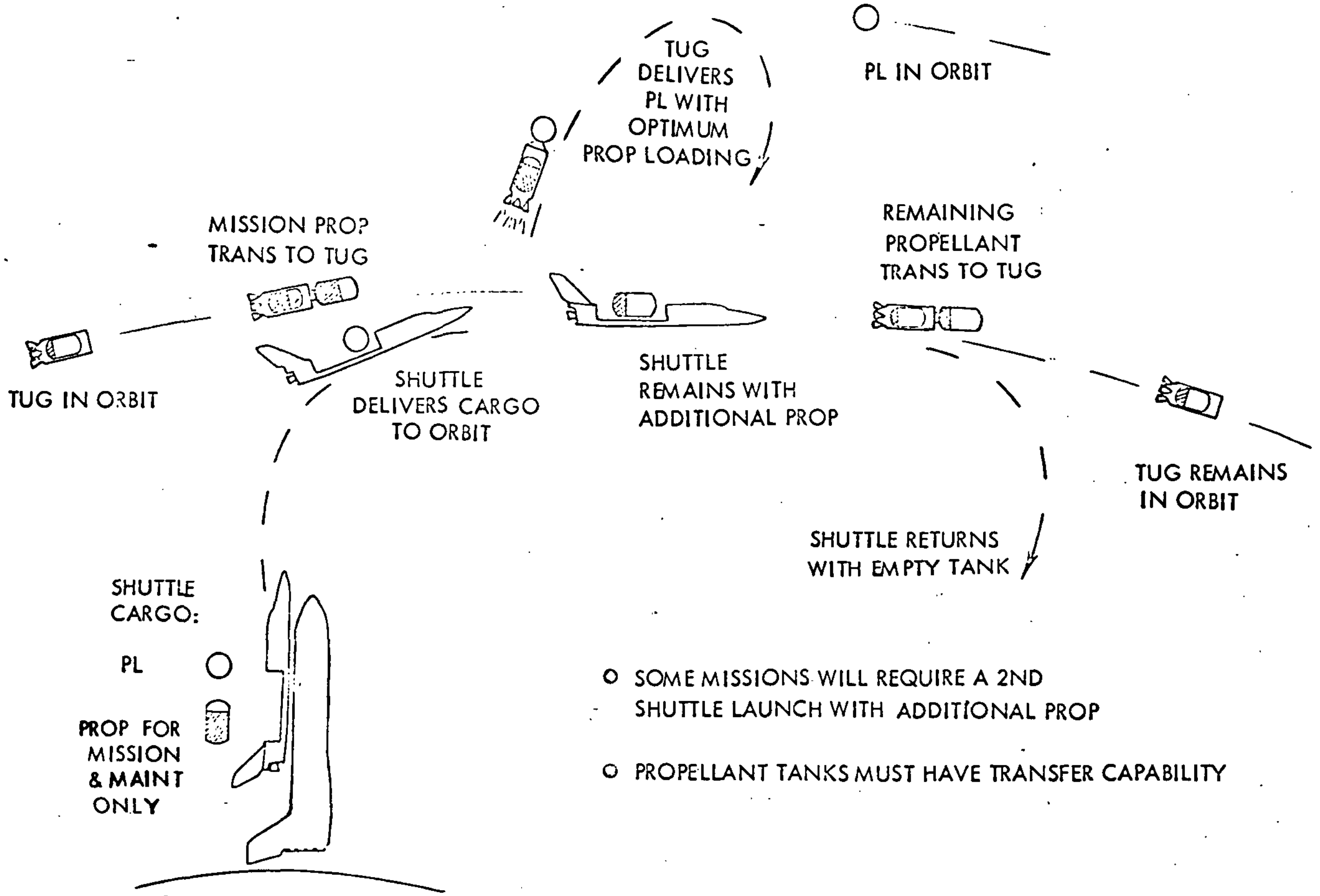


Figure 4.3-4 Operational Concept 1 for Payload Delivery With Space Based Tug, No Orbital Storage

the payload in orbit and returns to the shuttle, at which time propellant for orbital maintenance until the next shuttle launch is transferred to the tug. The shuttle has been held for the return of the tug from the payload placement mission in order to avoid the penalty of the tug carrying excess propellant on the placement mission. A second shuttle launch will be required to carry enough propellant to orbit for many of the payload placement missions.

The concept of operating with no orbital storage represents the simplest approach to propellant logistics considering only the number of elements required. It is anticipated that operational costs would be high in that utilization of the shuttle is poor. This concept should represent an extreme of those under consideration.

Concept 2. Space-Based Tug - Self Storage - Full Shuttle Payload (Figure 4.3-5). This concept is very similar to Concept 1 with the exception that the shuttle would always carry a full 65,000-pound payload to orbit. The initial transfer of propellant to the tug for the intended mission would be the same as in Concept 1. The second transfer of propellant to the tug would consist of the remainder of the propellant carried to orbit by the shuttle.

The excess beyond that required for the tug orbital maintenance between missions would be applied to the next scientific payload placement.

The concept of carrying a full shuttle payload and storing extra propellant delivered in the orbiting tug represents an efficient operating mode. Further, it provides for operational flexibility in the event of unscheduled delays in the next shuttle launch. Comparison with Concept 1 should show the influence of orbital storage.

Concept 3. Space-Based Tug - Storage in Second Tug - Full Shuttle Payload (Figure 4.3-6).
Concept 3 is similar to Concept 2 except that two tugs are parked in orbit together. One, "mission tug", is nominally used for placement missions; the other, "storage tug", is used for orbital storage, although the role may be reversed as frequently as every mission depending on several factors. This concept provides more orbital storage capacity than Concept 2, but has the disadvantage of greater boiloff (i.e., two tugs versus one). Shuttle stay time in orbit would be less in that transfer operations could be completed without waiting for the tug to complete its mission.

Concept 4. Space-Based Tug - Orbital Depot - Full Shuttle Payload (Figure 4.3-7). Concept 4 uses a propellant storage facility rather than a second tug as in Concept 3. The storage facility could be any of the depot concepts described in Section 4.2. The shuttle orbiter would always carry a full 65,000 pound load consisting normally of the scientific payload plus propellant. On a particular shuttle flight, excesses of fuel over that required for the tug placement mission will be placed in the storage facility. Deficiencies, when they occur, will be drawn from storage. Occasionally, a shuttle flight with propellant alone may be required. The required size of the depot will be determined by examination of a continuous record of the propellant level in the depot as the concept is applied sequentially to the missions in the program

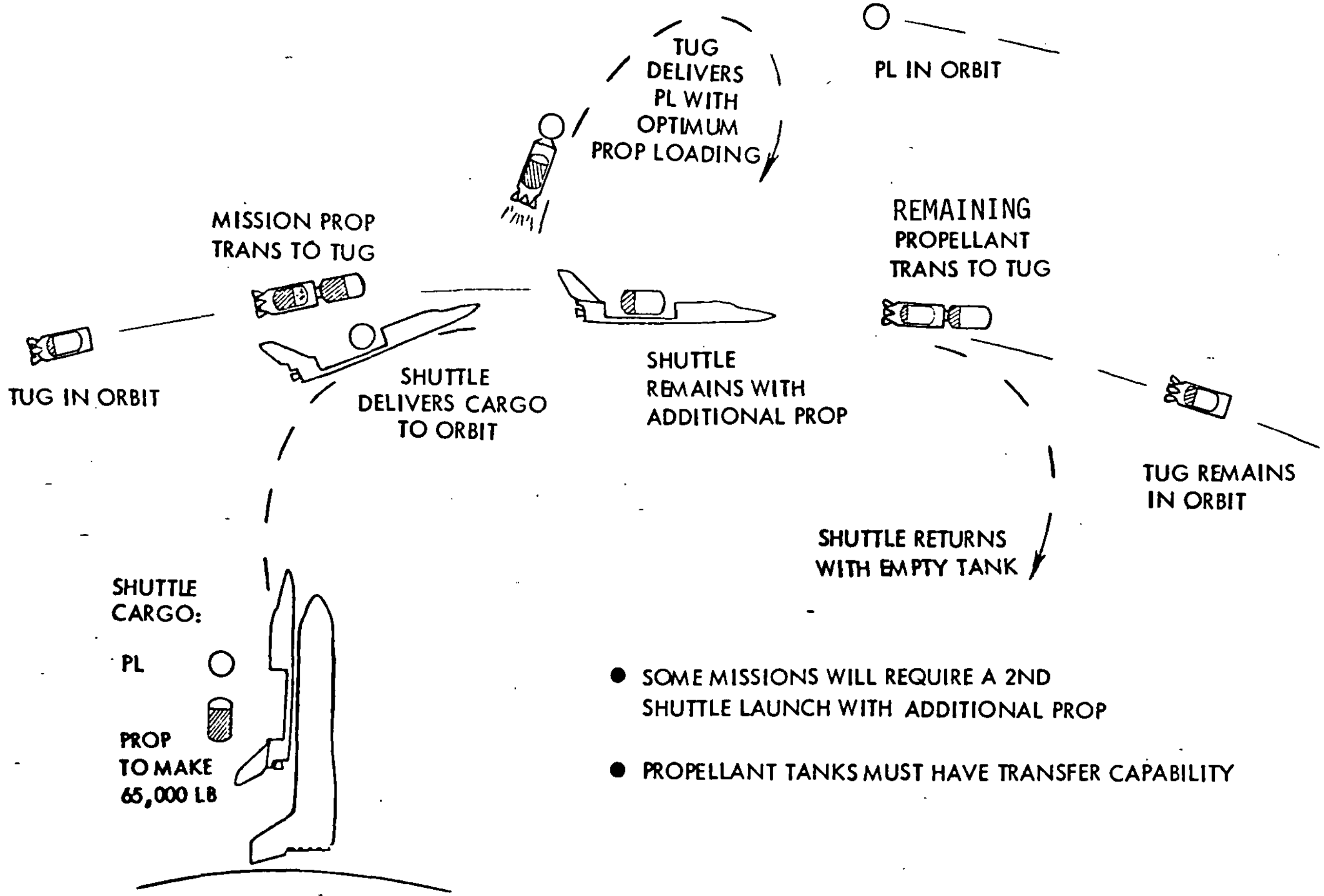


Figure 4.3-5 Operational Concept 2 for Payload Delivery With Space Based Tug, Self Storage

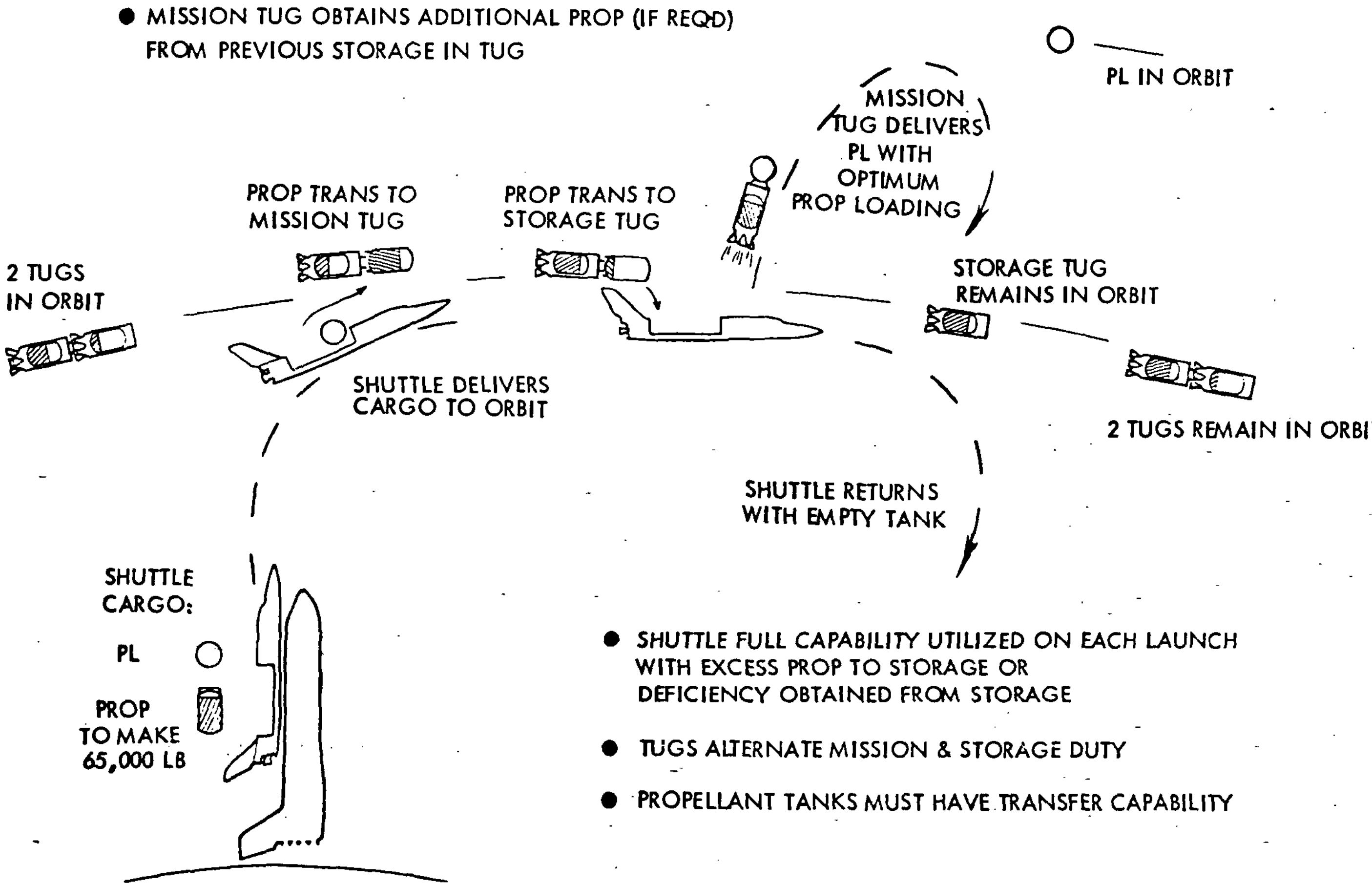


Figure 4.3-6 Operational Concept 3 for Payload Delivery With Space Based Tug, Orbital Storage Using Two Tugs

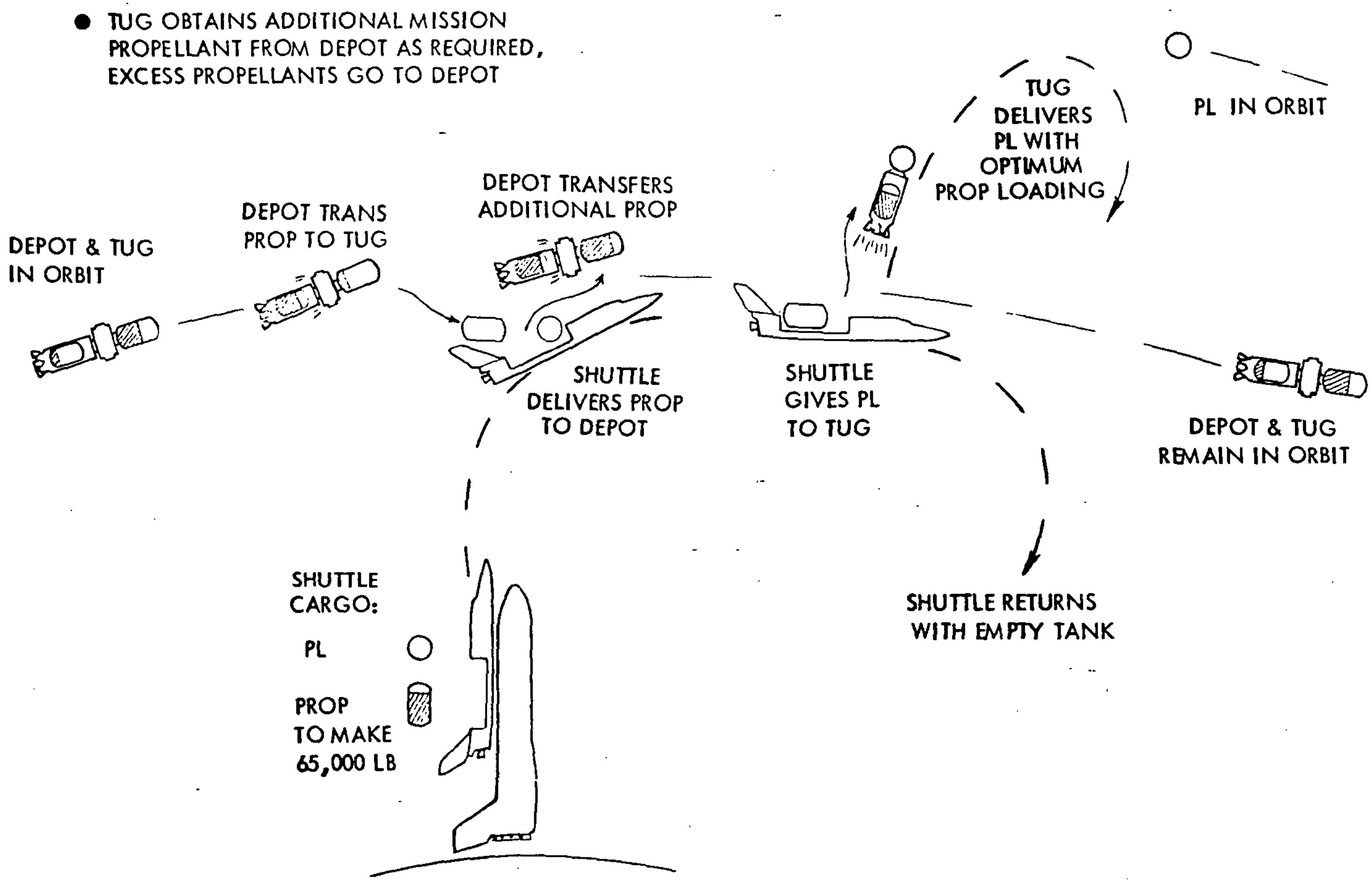


Figure 4.3-7 Operational Concept 4 for Payload Delivery With Space Based Tug, Orbital Storage Depot

levels. The concept permits the tug to be optimally loaded for each placement mission and not be penalized by carrying excess propellants. Orbital maintenance propellant will be derived from the depot. In this case, the shuttle is not required to be held in orbit until the return of the tug from its placement mission but can return to earth on completing its initial transfer of propellant and payload.

The concept of using an orbital propellant depot is fundamental for this study. It provides the basis for all comparisons. The need for orbital storage is established by comparing Concepts 1 and 4. The relative efficiency of various types of orbital storage is determined by comparing Concepts 2, 3, and 4.

Concept 5. Space-Based Tug - Orbital Depot - Separate Payload and Propellant Shuttle Flights (Figure 4.3-8).
Concept 5 considers delivery of scientific payload and propellant to orbit by separate shuttle flights. A tug and storage facility are maintained in orbit. Shuttles with "propellant only" loads deliver propellant to the storage facility. Other shuttle flights deliver payloads to tug for the placement missions. Since most placement payloads are relatively light (one or two thousand pounds), a shuttle flight to carry only one placement payload to orbit will be very expensive on a dollars per pound basis. However, consideration of this concept would indicate the penalties that might occur if the nature of the scientific payload would require a separate launch. Excessive growth of the scientific payload either in size or weight would cause a trend toward implementation of this mode of operation.

4.4 SCIENTIFIC PAYLOAD SHUTTLE CARGO SHARING

The operational concepts considered have all been based on the assumption that individual shuttle flights would be required for each scientific payload placement. That is, no more than one scientific payload would be in the shuttle cargo bay for a given flight and a payload propulsive stage would carry only one scientific payload. Examination of the payload placements indicates that many payloads are delivered to the same orbit, even during a given year of a program. Further, many of the payloads are small and relatively light such that some form of multiple delivery might be applied. This problem was reviewed in brief and the results are reported in Appendix E. These results indicate that shuttle flights can be reduced by 40 percent and on-orbit propellant requirements by 30 percent based on the program models developed in this study.

4.5 REFERENCE

4.2-1 "S-II Stage Orbital Propellant Storage System Feasibility Study", NR Space Division Report SD70-554, March 31, 1971 (Change Order 1980 to Contract NAS7-200)

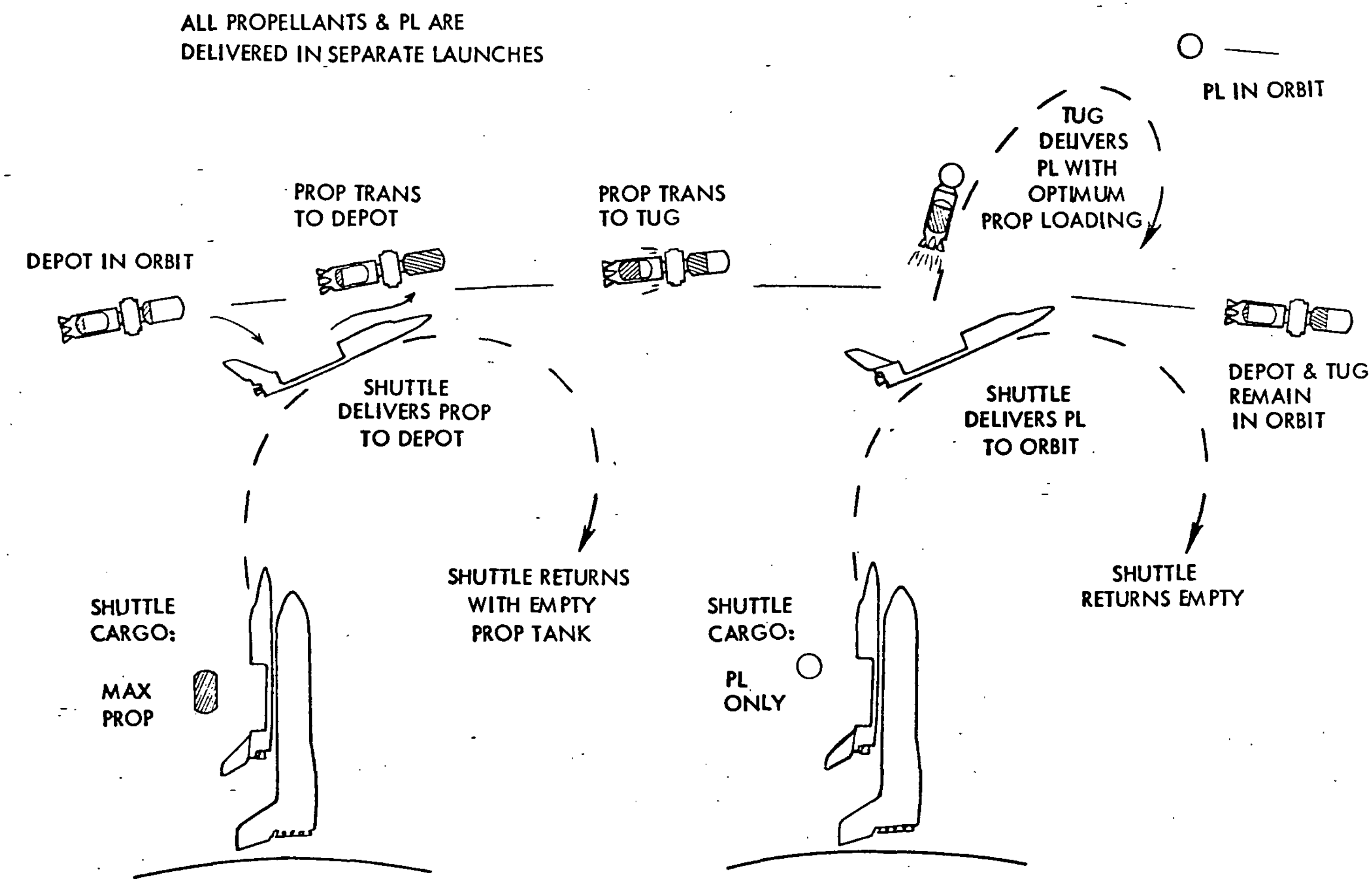


Figure 4.3-8 Operational Concept 5 for Payload Delivery With Space Based Tug, Orbital Storage, Separate Propellant & Payload Flights

5.0 PROPELLANT LOGISTICS TRAFFIC MODELS

Propellant logistics traffic models consist of the summation of the number of shuttle logistics flights to provide the propellants in support of payload propulsive stage flights in each space program activity level and for each applicable propellant logistics concept. Such traffic models are an element in the overall propellant logistics operations analysis; and they were established to provide data necessary for a comparison between candidate logistics concepts and for the selection of the most cost effective concept, as documented in Section 7.0.

In general, the traffic models for the two ground-based concepts developed in Section 4.0 were derived by an operations analysis method which assumed that each ground-based propulsive stage with its assigned scientific payload and necessary propellant for placement would be carried on the same shuttle flight. Shuttle flights in excess of the number of payload placements in any one program level are caused by a number of placements which exceed the single flight payload capability of the shuttle and/or the single stage delta-V capability of the Centaur or ground-based tug. The resulting logistics traffic models for the ground-based concepts are summarized in Figures 5.1-1 through 5.1-6.

The traffic models for four of the five space-based concepts developed in Section 4.0 were derived by an operations analysis method which assumed that each scientific payload would share the shuttle orbiter cargo bay with a propellant logistics module containing propellant for payload placement and in-orbit keeping of the space-based tug between placement missions. For one of the five space-based concepts, it was assumed that scientific payload and shuttle propellant logistics flight would be separate. In all five cases, the total number of required shuttle flights in each program level was influenced by the payload capability of the shuttle and the presence or absence of an orbital storage facility. Traffic models for the five space-based concepts under consideration are summarized in Figures 5.2-1 through 5.2-7.

The traffic model summaries, representing the 37 combinations of program level activity and propellant logistics concepts developed in Section 4.0, are presented in tabular form for easy identification of trends. In addition to their use in the comparative analysis of logistics concepts, the summaries may be employed for program planning purposes. The listing of the number of required shuttle and other reusable vehicle flights, as well as the number of expended vehicles, should be an aid in the determination of fleet sizes for various space program levels. Logistics traffic models for future space program plans, not covered by this study, may be obtained by additions to, or subtractions from, the data presented. This procedure is facilitated by the separate listing of CIS/RNS supportive shuttle flights, the grouping of space-based tug flights by orbit inclination, and the listing of special placement missions (those requiring two propulsive stages and those in which a reusable tug is expended).

5.1 GROUND-BASED CONCEPT ANALYSIS

Development of propellant logistics traffic models for the two ground-based concepts under consideration was performed in accordance with the Program Level Composition Guide of Table 3.2.3-1 and employed the ground-based vehicles defined in Figure 3.2.2-1. However, the analysis technique used in the development of the traffic models also took into account the shuttle flights required for CIS/RNS mission support in Program Levels D and E, although the CIS and RNS are space-based vehicles. The determination of the required number of shuttle flights and the number and types of vehicles expended was based on the following ground rules:

a. The least expensive of the non-reusable vehicles capable of performing a given mission is selected for that mission.

b. Payload placements that cannot be achieved with a single Centaur stage will be performed with two Centaurs assembled in orbit.

c. Payload placements that cannot be achieved with a single ground-based tug in the recovery mode will be performed with two tugs if both can be recovered.

d. Payload placements that cannot be achieved with two tugs in the recovery mode will be performed with one tug, considering this vehicle to be expended.

e. Mission No. 28 (Applications Technology Satellite) can be performed with two ground-based tugs, requiring two shuttle launches including the payload.

f. Mission No. 51, 59, and 60 (Mars Sample Return, Asteroid Survey, and Comet Rendezvous) require three shuttle launches each due to payload size and weight.

g. Manned lunar missions L-3 and L-4, CIS option, require 21 shuttle launches each for refueling, including payload propellant (85,000 pounds per mission) and boil-off makeup. An additional two shuttle launches per mission are required for the non-propellant payload (90,000 pounds). For the RNS option, 12 shuttle launches per mission will be required for refueling. (This shuttle flight support assumes that the CIS/RNS acts as its own storage facility while it is parked in earth orbit between lunar missions.)

h. Missions P-2 and P-3 (Venus Surface Sample and Mars Surface Sample), CIS option, require 10 shuttle launches each for propellant resupply, or seven shuttle launches each for the RNS option. Another three shuttle launches per mission are required for transporting the payload to the CIS/RNS parking orbit.

i. Mission P-4 (Jupiter Orbiter/Probes & Satellite Lander) requires 14 and 8 shuttle flights, respectively, for the CIS and RNS options and two shuttle flights are required for transporting the payload.

The propellant logistics traffic models developed under these ground rules are shown in Figures 5.1-1 through 5.1-5 for Program Levels A through E, respectively. They are summarized for all five program levels in Figure 5.1-6; and the methods used to derive the traffic models are illustrated for two different years in Program Level C in Figures 5.1-7 and 5.1-8. These represent the use of expendable vehicles and the reusable ground-based tug, respectively.

5.2 SPACE-BASED CONCEPT ANALYSIS

Traffic model summaries for the five logistics system operational concepts that include a space-based tug are shown in Figures 5.2-1 through 5.2-6 for Program Levels B_2, C_2, D_4, D_2, E_4, and E_2, respectively. They are summarized in Figure 5.2-7 for the 1985-1990 time period. These traffic model summaries were developed for the five operational concepts (space-based) described in Section 4.0 and are subject to the following ground rules and assumptions:

a. The logistics tank for transporting propellants in the shuttle cargo bay is 15 feet in diameter by 38 feet long, weighs 5100 pounds dry, and has a maximum propellant capacity of 59,900 pounds.

b. The loss during transfer of propellant from the logistics tank to the space-based tug is 4 percent of the quantity transferred.

c. Propellant required for tug boil-off and orbit maintenance between payload placement missions is 100 pounds per day.

d. Average time to complete a payload placement mission is two days.

e. Payload placements that cannot be achieved with a single space-based tug in the recovery mode will be performed with two tugs if both can be recovered (Missions No. 28, 51, 59, and 60).

f. Payload placements that cannot be achieved with two tugs in the recovery mode will be performed with one tug, considering this vehicle to be expended (Missions No. 55, 57, 58, and 60-3).

g. Only one "mission" tug is considered to be in orbit at all times. Hence, for any mission requiring two tugs, a partially fueled tug is counted as one shuttle payload chargeable against that mission.

h. The payload for Mission No. 28 can be carried on the same shuttle flight that contains propellant for the space-based tug.

PLACEMENTS WITH	NO. OF MISSIONS	NO. OF PPS FLIGHTS	NO. OF SHUTTLE FLIGHTS
AGENA	100	100	100
FW-4S DERIVATIVE	43	43	43
CENTAUR D-IT STS	14	14	14
2 CENTAURS D-IT STS	11	22	27
TOTAL	168	179	184

Figure 5.1-1 Program Level A_1 - Traffic Model Summary
Ground Based Concept

PLACEMENTS WITH	1979-1984			1985-1990		
	NO. OF MISSIONS	NO. OF PPS FLIGHTS	NO. OF SHUTTLE FLIGHTS	NO. OF MISSIONS	NO. OF PPS FLIGHTS	NO. OF SHUTTLE FLIGHTS
AGENA	80	80	80	—	—	—
FW-4S DERIVATIVE	30	30	30	—	—	—
CENTAUR D-IT STS	9	9	9	—	—	—
2 CENTAURS D-IT STS	4	8	10	—	—	—
GROUND-BASED TUG	—	—	—	108	108	108
2 GROUND-BASED TUGS	—	—	—	5	10	13
GROUND-BASED TUG, NOT RECOV	—	—	—	4	4	4
TOTAL	123	127	129	117	122	125

Figure 5.1-2 Program Level B_1 - Traffic Model Summary
Ground Based Concept

PLACEMENTS WITH	1979 - 1984			1985 - 1990		
	NO. OF MISSIONS	NO. OF PPS FLIGHTS	NO. OF SHUTTLE FLIGHTS	NO. OF MISSIONS	NO. OF PPS FLIGHTS	NO. OF SHUTTLE FLIGHTS
AGENA	102	102	102	—	—	—
FW-4S DERIVATIVE	40	40	40	—	—	—
CENTAUR D-IT STS	10	10	10	—	—	—
2 CENTAURS D-IT STS	4	8	10	—	—	—
GROUND-BASED TUG	—	—	—	147	147	147
2 GROUND-BASED TUGS	—	—	—	6	12	15
GROUND-BASED TUG, NOT RECOV	—	—	—	4	4	4
TOTAL	156	160	162	157	163	166

Figure 5.1-3 Program Level C_1 - Traffic Model Summary
Ground Based Concept

PLACEMENTS WITH	1979-1984			1979-1984			1985-1990		
	NO. OF MISSIONS	NO. OF PPS FLIGHTS	NO. OF SHUTTLE FLIGHTS	NO. OF MISSIONS	NO. OF PPS FLIGHTS	NO. OF SHUTTLE FLIGHTS	NO. OF MISSIONS	NO. OF PPS FLIGHTS	NO. OF SHUTTLE FLIGHTS
AGENA	147	147	147	—	—	—	—	—	—
FW-4S DERIVATIVE	40	40	40	—	—	—	—	—	—
CENTAUR D-IT STS	27	27	27	—	—	—	—	—	—
2 CENTAURS D-IT STS	4	8	10	—	—	—	—	—	—
GROUND-BASED TUG	—	—	—	206	206	206	200	200	200
2 GROUND-BASED TUGS	—	—	—	8	16	18	6	12	15
GROUND-BASED TUG, NOT RECOV	—	—	—	4	4	4	5	5	5
CIS/RNS	—	—	—	—	—	—	10	10	230/140*
TOTAL	218	222	224	218	226	228	221	227	450/360

*LUNAR MISSIONS IN MODE 1 OPERATION

Figure 5.1-4 Program Level D - Traffic Model Summary
Ground Based Concept

PLACEMENTS WITH	1979-1984			1979-1984			1985-1990		
	NO. OF MISSIONS	NO. OF PPS FLIGHTS	NO. OF SHUTTLE FLIGHTS	NO. OF MISSIONS	NO. OF PPS FLIGHTS	NO. OF SHUTTLE FLIGHTS	NO. OF MISSIONS	NO. OF PPS FLIGHTS	NO. OF SHUTTLE FLIGHTS
AGENA	147	147	147	—	—	—	—	—	—
FW-4S DERIVATIVE	40	40	40	—	—	—	—	—	—
CENTAUR D-IT STS	27	27	27	—	—	—	—	—	—
2 CENTAURS D-IT STS	4	8	10	—	—	—	—	—	—
GROUND-BASED TUG	—	—	—	206	206	206	198	198	198
2 GROUND-BASED TUGS	—	—	—	8	16	18	4	8	9
GROUND-BASED TUG, NOT RECOV.	—	—	—	4	4	4	4	4	4
CIS/RNS	1	1	13/10	1	1	13/10	14	14	288/180*
TOTAL	219	223	237/234	219	227	241/238	220	224	499/391

*LUNAR MISSIONS IN MODE 1 OPERATION

Figure 5.1-5 Program Level E - Traffic Model Summary
Ground Based Concept

	PROGRAM LEVEL						
	A_1	B_1	C_1	D_1	D_3	E_1	E_3
PAYLOAD PLACEMENTS	168	240	313	439	439	439	439
NO. OF SHUTTLE FLIGHTS	184	254	328	628/538*	632/542*	677/566*	681/570*
AGENA FLIGHTS	100	80	102	147	0	147	0
CENTAUR D-IT STS FLIGHTS	14	9	10	27	0	27	0
FW-4S DERIVATIVE FLIGHTS	43	30	40	40	0	40	0
GROUND-BASED TUG FLIGHTS	0	108	147	200	406	198	404
TUGS NOT RECOVERED	0	4	4	5	9	4	8
PLACEMENTS REQUIRING 2 TUGS	0	5	6	6	14	4	12
PLACEMENTS REQUIRING 2 CENTAURS	11	4	4	4	0	4	0
TUG AVAILABLE	--	1985	1985	1985	1979	1985	1979
SHUTTLE FLIGHTS FOR CIS/RNS P.L.	--	--	--	40	40	53	53

*CIS/RNS (LUNAR MISSIONS IN MODE 1 OPERATION)

Figure 5.1-6 Traffic Model Summary Ground-Based Concept

MISSION NO.	NO. OF PLACEMENTS	PAYLOAD PROPULSIVE STAGE	NO. OF SHUTTLE FLIGHTS
3	1	AGENA	1
4	1	AGENA	1
5	1	AGENA	1
21	1	FW-4S	1
28	1	CENTAUR	1
29	1	AGENA	1
30	1	FW-4S	1
31	1	AGENA	1
33	2	AGENA	2
36	1	AGENA	1
50	1	CENTAUR	1
56	2	2 CENTAURS	4
70	2	AGENA	2
71	1	AGENA	1
73	3	AGENA	3
75	1	FW-4S	1
76	1	AGENA	1
77	4	FW-4S	4
TOTAL	26	AGENA - 15 FW-4S - 7 CENTAUR - 2 2 CENTAURS - 2	28

Figure 5.1-7 Traffic Model Derivation -
Program Level C_1 - 1979

MISSION NO.	NO. OF PLACEMENTS	NO. OF SHUTTLE FLIGHTS
2	2	2
3	1	1
4	1	1
5	1	1
21	1	1
23	1	1
25	1	1
29	1	1
30	1	1
35	2	2
54	1	1
57	1	1 ← TUG NOT RECOVERED
60	1	3 ← 2-TUG PLACEMENT
70	1	1
71	2	2
73	1	1
74	1	1
75	1	1
76	1	1
77	4	4
78	4	4
TOTAL	30	32

Figure 5.1-8 Traffic Model Derivation
Program Level C_1 - 1985

PLACEMENTS WITH	NUMBER OF MISSIONS	NUMBER OF SB TUG FLIGHTS	NUMBER OF SHUTTLE FLIGHTS OPERATIONS CONCEPT 1	2	3	4	5
SPACE-BASED TUG							
0° - 30° INCL.	72	72	123	84	85	85	
55° INCL.	3	3	3	3	3	3	
90° - 100.7° INCL.	33	33	35	35	35	35	46
TWO SPACE-BASED TUGS							
0° - 30° INCL.	5	10	13	13	13	13	
SPACE-BASED TUG, NOT RECOV.							
30° INCL.	4	4	6	4	4	4	
TOTAL	117	122	180	139	140	140	233

Figure 5.2-1 Program Level B_2 - 1985-1990 Traffic Model Summary
Space-Based Tug Operations Concepts

PLACEMENTS WITH	NUMBER OF MISSIONS	NUMBER OF SB TUG FLIGHTS	NUMBER OF SHUTTLE FLIGHTS				
				OPERATIONS CONCEPT			
			1	2	3	4	5
SPACE-BASED TUG							
0°-30° INCL.	95	95	164	109	111	111	
55° INCL.	6	6	6	6	6	6	
90° - 100.7° INCL.	46	46	50	50	50	50	
TWO SPACE-BASED TUGS							
0° - 30° INCL.	6	12	15	15	15	15	
SPACE-BASED TUG, NOT RECOV.							
30° INCL.	4	4	6	4	4	4	
TOTAL	157	163	241	184	186	186	307

Figure 5.2-2 Program Level C_2 - 1985-1990 Traffic Model Summary
Space-Based Tug Operations Concepts

PLACEMENTS WITH	NUMBER OF MISSIONS	NUMBER OF SB TUG FLIGHTS	NUMBER OF SHUTTLE FLIGHTS — OPERATIONS CONCEPT 1	2	3	4	5
SPACE-BASED TUG							
0° - 30° INCL.	164	164	295	184	184	184	
55° INCL.	3	3	3	3	3	3	
90 - 100.7° INCL.	39	39	41	41	41	41	52
TWO SPACE-BASED TUGS							
0° - 30° INCL.	8	16	18	18	18	18	
SPACE-BASED TUG, NOT RECOV.							
30° INCL.	4	4	4	4	4	4	
TOTAL	218	226	361	250	250	250	448

Figure 5.2-3 Program Level D_4 - 1979-1984 Traffic Model Summary
Space-Based Tug Operations Concepts

PLACEMENTS WITH	NO. OF MISSIONS	NO. OF PPS FLIGHTS	NUMBER OF SHUTTLE FLIGHTS — OPERATIONS CONCEPT 1	2	3	4	5
SPACE-BASED TUG							
0°-30° INCL.	148	148	271	171	173	173	
55° INCL.	6	6	6	6	6	6	
90° - 100.7° INCL.	46	46	50	50	50	50	62
TWO SPACE-BASED TUGS							
0° - 30° INCL.	6	12	15	15	15	15	
SPACE-BASED TUG, NOT RECOV.							
30° INCL.	5	5	8	5	5	5	
CIS/RNS*	10	10	230/140	230/140	230/140	230/140	230/140
TOTAL	221	227	580/490	477/387	479/389	479/389	656/566

*LUNAR MISSIONS IN MODE 1 OPERATION

Figure 5.2-4 Program Level D_2 - 1985-1990 Traffic Model Summary
Space-Based Tug Operations Concepts

PLACEMENTS WITH	NUMBER OF MISSIONS	NUMBER OF PPS FLIGHTS	NUMBER OF SHUTTLE FLIGHTS OPERATIONS CONCEPT				
			1	2	3	4	5
SPACE-BASED TUG							
0° - 30° INCL.	164	164	295	184	184	184	
55° INCL.	3	3	3	3	3	3	
90° - 100.7° INCL.	39	39	41	41	41	41	52
TWO SPACE-BASED TUGS							
0° - 30° INCL.	8	16	18	18	18	18	
SPACE-BASED TUG, NOT RECOV.							
30° INCL.	4	4	4	4	4	4	
CIS/RNS	1	1	13/10	13/10	13/10	13/10	13/10
TOTAL	219	227	374/371	263/260	263/260	263/260	461/458

Figure 5.2-5 Program Level E_4 - 1979-1984 Traffic Model Summary
Space-Based Tug Operations Concepts

PLACEMENTS WITH	NUMBER OF MISSIONS	NUMBER OF PPS FLIGHTS	NUMBER OF SHUTTLE FLIGHTS OPERATIONS CONCEPT 1	2	3	4	5
SPACE-BASED TUG							
0° - 30° INCL.	146	146	267	169	170	170	
55° INCL.	6	6	6	6	6	6	
90° - 100.7° INCL.	46	46	50	50	50	50	62
TWO SPACE-BASED TUGS							
0° - 30° INCL.	4	8	9	9	9	9	
SPACE-BASED TUG, NOT RECOV.							
30° INCL.	4	4	7	4	4	4	
CIS/RNS*	14	14	288/180	288/180	288/180	288/180	288/180
TOTAL	220	224	627/519	526/418	527/419	527/419	698/590

*LUNAR MISSIONS IN MODE 1 OPERATION

Figure 5.2-6 Progral Level E_2 - 1985-1990 Traffic Model Summary
Space-Based Tug Operations Concepts

SB TUG OPERATING CONCEPT COMPARISONS
1985 - 1990

PROGRAM LEVEL			B_2	C_2	D_2	E_2
PAYLOAD PLACEMENTS			117	157	211	206
SINGLE SB TUG FLIGHTS			108	147	200	198
DOUBLE SB TUG FLIGHTS			5	6	6	4
EXPENDED SB TUG FLIGHTS			4	4	5	4
NUMBER OF SHUTTLE FLIGHTS	CONCEPT 1	NO DEPOT MIN LOAD	180	241	350	339
	CONCEPT 2	NO DEPOT MAX LOAD	139	184	247	238
	CONCEPT 3	TWO TUG MAX LOAD	140	186	249	239
	CONCEPT 4	DEPOT MAX LOAD	140	186	249	239
	CONCEPT 5	DEPOT SEPARATE PAYLOAD AND PROPELLANT	233	307	426	410
	CIS/RNS	LUNAR MISSIONS IN MODE 1 OPERATION	0	0	230/140	288/180

Figure 5.2-7 Propellant Logistics Traffic Model Summary

i. Missions No. 51, 59, and 60 require three shuttle launches each, due to scientific payload size and weight.

j. The number of shuttle flights required for Missions No. L-3, L-4, P-2, P-3, and P-4 is the same as was derived for the traffic model summaries with ground-based payload propulsive stages.

In the analysis of Concepts 2, 3, and 4, it was assumed that an orbital storage facility (single space-based tug, two tugs, or mini-depot) would serve to support only those payload placement missions with orbit inclinations between zero and 30 degrees. These represent the major portion of the missions under consideration. Missions to other orbit inclinations (55-, 90-, 99.15-, and 100.7 degrees) are too few and occur too infrequently to justify consideration of separate orbital storage facilities. Besides, with the exception of Missions No. 4D and 5D, all the missions to 55 degrees and the polar orbits can be performed by a fueled, space-based tug carried in the shuttle cargo bay (as with a ground-based tug) with its scientific payload. Hence, only six shuttle flights would be saved in Program Levels C, D, or E by the introduction of a polar orbit storage facility; and this number must be reduced by the shuttle flights required for supplying propellant necessary for boil-off and orbit maintenance for both the tug and the storage facility.

To arrive at the quantity of propellant required from an orbital storage facility for payload placement, shuttle flights for affected missions were examined with regard to excess propellant available for transfer to the storage facility, or propellant deficiencies to be supplied to the tug from storage. The results of this analysis are summarized in the two-page Table 5.2-1. They indicate a maximum single flight excess of 51,500 pounds and a maximum deficiency of 21,800 pounds. In connection with the net quantity of propellant required from the storage facility, it should be noted that the traffic model summaries of Figures 5.2-1 through 5.2-7 do include the shuttle flights required for transporting this net deficiency from the ground to the storage facility; and allowance has been made for boil-off losses and orbit maintenance expenditures imposed by the storage facility.

The traffic model summaries for Concepts 1, 2, 4, and 5 were established for a random sequence of payload placement missions within any one year and program level, i.e., placements were scheduled in Fleming Model numerical order. If it is assumed, however, that sequencing of missions can be arranged such that shuttle flights with excess propellant alternate with those on which a deficiency exists, then the Concept 4 traffic model is also valid for Concept 3.

In the operation of Concept 2, whenever the quantity of propellants remaining in the tug plus the quantity to be delivered with the next scientific payload is insufficient for the placement of this payload, a separate shuttle flight carrying only propellant is made first. This propellant is transferred to the tug prior to delivery of the scientific payload to orbit; however, at no time is the quantity of propellants in the tug permitted to rise above the level required for the next placement mission. This restriction results in some shuttle flights being off-loaded to prevent the accumulation of propellant that is not needed, but the overall shuttle weight utilization remains high.

Table 5.2-1 Summary of Orbital Propellant Depot Supplies and Withdrawals

65,000 LB SHUTTLE CAPABILITY
4% TRANSFER LOSS
SPACE-BASED TUG PROPELLANT REQUIREMENTS
0° - 30° ORBIT INCLINATION MISSIONS

MISSION NUMBER	PAYLOAD (LB)	PROPELLANT REQD (LB)	PROPELLANT AVAIL (LB)	EXCESS TO STORAGE (LB)	DEFICIENCY (LB)	
2	720	54,500	56,800	2,300		
3A	1,200	49,500	56,300	6,800		
3B	1,200	4,800	56,300	51,500		
4A	1,000	40,100	56,500	16,400		
4B	1,000	37,100	56,500	19,400		
5A	600	55,300	56,900	1,600		
5B	600	38,500	56,900	18,400		
8	500	38,400	57,000	18,600		
9	6,000	69,400	51,700		17,700	
10	1,900	55,500	55,700	200		
11	1,900	40,100	55,700	15,600		
12	3,500	57,900	54,100		3,800	
22	1,000	65,800	56,500		9,300	
24	1,000	65,800	56,500		9,300	
27	1,000	65,800	56,500		9,300	
28	7,950	78,800	104,700	25,900		*
29	600	65,200	56,900		8,300	
31	820	65,500	56,700		8,800	
33	2,000	67,500	55,500		12,000	
34	2,145	67,800	55,400		12,400	
35	2,000	67,500	55,500		12,000	
36	2,300	68,000	55,300		12,700	
37	1,000	65,800	56,500		9,300	
50	7,700	99,600	104,900	5,300		*
51	22,000	134,100	112,300		21,800	**
52	1,000	58,700	56,500		2,200	
53	7,900	69,600	49,900		19,700	
54	7,300	68,600	50,500		18,100	
55	900	43,800	56,600	12,800		

*2 SHUTTLE FLIGHTS
**3 SHUTTLE FLIGHTS

Table 5.2-1 Summary of Orbital Propellant Depot Supplies and Withdrawals (Continued)

65,000 LB SHUTTLE CAPABILITY
4% TRANSFER LOSS
SPACE-BASED TUG PROPELLANT REQUIREMENTS
0° - 30° ORBIT INCLINATION MISSIONS

MISSION NUMBER	PAYLOAD (LB)	PROPELLANT REQD (LB)	PROPELLANT AVAIL. (LB)	EXCESS TO STORAGE (LB)	DEFICIENCY (LB)	
56	1,500	60,900	56,000		4,900	
57	3,300	53,300	54,300	1,000		
58	3,700	61,500	53,900		7,600	
59	27,000	105,200	112,300	7,100		**
60	24,000	99,500	112,300	12,800		**
60-3	4,050	71,600	53,600		18,000	
70	1,420	66,500	56,200		10,300	
71	2,145	67,800	55,400		12,400	
72	1,000	55,000	56,500	1,500		
73	700	63,700	56,800		6,900	
74	700	58,300	56,800		1,500	
76	1,000	65,800	56,500		9,300	
78	1,000	65,800	56,500		9,300	
78-2	850	65,600	56,600		9,000	
78-3	2,500	68,400	55,100		13,300	
78-4	1,000	65,800	56,500		9,300	
L-1	1,600	35,700	56,000	20,300		
L-2	16,500	51,800	41,700		10,100	

** 3 SHUTTLE FLIGHTS

The Concept 5 analysis was made under the assumption that shuttle propellant flights to orbit inclinations between 28.5 degrees and 55 degrees will always contain the maximum payload weight of 65,000 pounds, and will deliver a net quantity (after allowance for transfer losses) of 57,500 pounds either to the space-based tug or an orbital storage facility. The total number of shuttle propellant flights was established on the basis of total tug propellant requirements for payload placements plus propellants lost through boil-off and orbit maintenance for both the tug and the orbital storage facility.

Examination of the Figure 5.2-7 summary shows that, from a traffic model standpoint, Concepts 2, 3, and 4 are identical and involve significantly fewer shuttle flights than Concept 1 or 5.

The methods used to derive the traffic models are illustrated for the year 1985 in Program Level C in Figures 5.2-8 through 5.2-11.

MISSION NO.	ORBIT INCLINATION	NO. OF PLACEMENTS	*SHUTTLE CARGO LOAD, POUNDS	NO. OF SHUTTLE FLIGHTS	
2	28.5°	2	64,400	2	
3	55°	1	13,200	1	
4	55°	1	46,600	1	
5	55°	1	47,700	1	
21	99.15°	1	12,100	1	
23	90°	1	9,400	1	
25	100.7°	1	11,600	1	
29	0°	1	75,500**	2	
30	90°	1	15,800	1	
35	0°	2	79,300**	4	
54	30°	1	85,700**	2	
57	30°	1	65,800	1	TUG NOT RECOVERED
60	30°	1	134,800**	3	2-TUG PLACEMENT
70	0°	1	77,700**	2	
71	0°	2	79,700**	4	
73	29°	1	74,100**	2	
74	5°	1	68,400**	2	
75	100.7°	1	11,600	1	
76	0°	1	76,600**	2	
77	99.15°	4	12,100	4	
78	0°	4	76,600**	8	
TOTAL		30		46	

*SHUTTLE CARGO LOAD = SCIENTIFIC PAYLOAD
+ SINGLE MISSION PROPELLANT
+ TUG MAINTENANCE PROPELLANT (1800 LBS)
+ PROPELLANT TRANSFER LOSS

**EXCEEDS 65,000-POUND SINGLE SHUTTLE CAPACITY

Figure 5.2-8 Traffic Model Derivation
Program Level C_2 - 1985 - Operations Concept 1

SHUTTLE FLIGHT NO.	TUG PROPELLANT SUMMARY POUNDS	SOURCE OF PROPELLANT ADDITION OR USAGE
1	+ 2300	MISSION 2
	- 1800	ORBIT MAKEUP AND BOILOFF
	500	
2	+ 2300	MISSION 2
	2800	
	- 1800	ORBIT MAKEUP AND BOILOFF
	1000	
3	+57500	"PROPELLANT ONLY" SHUTTLE FLIGHT
	58500	
4	- 8300	MISSION 29
	50200	
	- 1800	ORBIT MAKEUP AND BOILOFF
	48400	
5	-12000	MISSION 35
	36400	
	- 1800	ORBIT MAKEUP AND BOILOFF
	34600	
6	-12000	MISSION 35
	22600	
	- 1800	ORBIT MAKEUP AND BOILOFF
	20800	
7	-18100	MISSION 54
	2700	
	- 1800	ORBIT MAKEUP AND BOILOFF
	900	
8	+ 1000	MISSION 57
	1900	
	- 1800	ORBIT MAKEUP AND BOILOFF
	100	
9	+54800	MISSION 60 PROPELLANT IN SECOND TUG
10	+57500	"PROPELLANT ONLY" SHUTTLE FLIGHT
	112400	
	- 99500	TOTAL MISSION 60 PROPELLANT CONSUMPTION
	12900	
	- 1800	ORBIT MAKEUP AND BOILOFF
	11100	

Figure 5.2-9 Traffic Model Derivation
Program Level C_2 - 1985 - Operations Concept 2

SHUTTLE FLIGHT NO.	TUG PROPELLANT SUMMARY, POUNDS	SOURCE OF PROPELLANT ADDITION OR USAGE
	11100	
11	- 10300	MISSION 70
	800	
12	+ 57500	"PROPELLANT ONLY" SHUTTLE FLIGHT
	58300	
	- 1800	ORBIT MAKEUP AND BOILOFF
	56500	
13	- 12400	MISSION 71
	44100	
	- 1800	ORBIT MAKEUP AND BOILOFF
	42300	
14	- 12400	MISSION 71
	29900	
	- 1800	ORBIT MAKEUP AND BOILOFF
	28100	
15	- 6900	MISSION 73
	21200	
	- 1800	ORBIT MAKEUP AND BOILOFF
	19400	
16	- 1500	MISSION 74
	17900	
	- 1800	ORBIT MAKEUP AND BOILOFF
	16100	
17	- 9300	MISSION 76
	6800	
	- 1800	ORBIT MAKEUP AND BOILOFF
	5000	
18	+ 57500	"PROPELLANT ONLY" SHUTTLE FLIGHT
	62500	
19	- 9300	MISSION 78
	53200	
	- 1800	ORBIT MAKEUP AND BOILOFF
	51400	
20	- 9300	MISSION 78
	42100	
	- 1800	ORBIT MAKEUP AND BOILOFF
	40300	

Figure 5.2-9 (Cont.)

SHUTTLE FLIGHT NO.	TUG PROPELLANT SUMMARY POUNDS	SOURCE OF PROPELLANT ADDITION OR USAGE
	40300	
21	- 9300	MISSION 78
	31000	
	- 1800	ORBIT MAKEUP AND BOILOFF
	29200	
22	- 9300	MISSION 78
	19900	
	- 1800	ORBIT MAKEUP AND BOILOFF
	18100	AVAILABLE FOR PLACEMENTS IN 1986
23		PAYLOAD FOR MISSION 60
24 ↕ 35		FLIGHTS FOR MISSIONS 3, 4, 5, 21, 23, 25, 30, 75, AND 77

Figure 5.2-9 (Cont.)

MISSION NO.	EXCESS PROPELLANT POUNDS	PROPELLANT DEFICIENCY POUNDS	SHUTTLE FLIGHT NO.
2	2300		1
2	2300		2
29		8300	3
35		12000	4
35		12000	5
54		18100	6
57	1000		7
60	12800		8,9,&10
70		10300	11
71		12400	12
71		12400	13
73		6900	14
74		1500	15
76		9300	16
78		9300	17
78		9300	18
78		9300	19
78		9300	20
	18400	140400	

0 - 30° INCLINATION MISSIONS

NET DEFICIENCY	= 140,400-18,400
	= 122,000 LBS
ORBIT MAINT. + BOILOFF	= 32,900 LBS
DEPOT MAINT. + BOILOFF	= 36,500 LBS
TOTAL DEFICIENCY	= 191,400 LBS
	= 3.33 DEDICATED SHUTTLE FLIGHTS

SHUTTLE SUMMARY

0-30° INCLINATION MISSIONS	20
55° INCLINATION & POLAR ORBIT MISSIONS	12
DEDICATED PROPELLANT FLIGHTS	3.33
TOTAL	35.33

Figure 5.2-10 Traffic Model Derivation

Program Level C_2 - 1985 - Operations Concept 4

0° - 55° INCLINATION MISSIONS		
MISSION NO.	NO. OF PLACEMENTS	PPS PROP. REQMTS POUNDS
2	2	109,086
3	1	4,817
4	1	37,104
5	1	38,536
29	1	65,154
35	2	135,066
54	1	68,613
57	1	53,286
60	1	99,500
70	1	66,548
71	2	135,560
73	1	63,729
74	1	58,253
76	1	65,834
78	4	263,336
TOTAL	21	1,264,422

PROPELLANT REQUIREMENT INCLUDING 4% TRANSFER LOSS $= \frac{1,264,000}{0.96}$

= 1,318,000 LBS

POLAR ORBIT MISSIONS		
MISSION NO.	NO. OF PLACEMENTS	PPS PROP. REQMTS POUNDS
21	1	2,470
23	1	1,704
25	1	3,535
30	1	7,865
75	1	3,535
77	4	9,880
TOTAL	9	28,989

PROPELLANT REQUIREMENT, INCLUDING 4% TRANSFER LOSS $= \frac{28,989}{0.96}$

= 30,200 LBS

ORBITAL STORAGE FACILITY MAINTENANCE = 36,500

TUG MAINTENANCE = 34,700

TOTAL PROPELLANT = 101,400 LBS

= 1.77 SHUTTLE FLIGHTS

Figure 5.2-11 Traffic Model Derivation
Program Level C_2 - 1985 - Operations Concept 5

TUG PROPELLANT REQUIREMENT	=	1,318,000 LBS
ORBITAL STORAGE FACILITY MAINTENANCE	=	36,500
TUG MAINTENANCE	=	32,300
TOTAL PROPELLANT	=	1,386,800 LBS
	=	24.1 SHUTTLE FLIGHTS

SHUTTLE FLIGHT SUMMARY

PAYLOAD FLIGHTS, 0 - 55°	21
PAYLOAD FLIGHTS, POLAR	9
PROPELLANT FLIGHTS, 0-55°	24.1
PROPELLANT FLIGHTS, POLAR	1.8
TOTAL	55.9

Figure 5.2-11 Program Level C_2 - 1985 - Operations Concept 5 (Cont.)

6.0 PROPELLANT TRANSFER ANALYSIS

The propellant transfer analysis for the ISPLS Study required that a comprehensive investigation be conducted to define the techniques, interface requirements, functional characteristics, and general configurational requirements for the various propellant logistics concepts developed. In general, the controlling criterion was delivery of propellants from the ground to space based payload propulsive stages using the space shuttle as the primary delivery vehicle.

The objectives of the propellant transfer analysis were: (1) to identify and evaluate the techniques which are suitable for the transfer of large quantities of cryogenic propellants between orbiting vehicles and to identify the basic subsystem or control functions required to achieve satisfactory propellant transfer characteristics; (2) to select the most competitive techniques and associated data for use in the development of the ISPLS cost effectivity and operational analyses; and (3) to select the technique and associated subsystem control functions which, from a technical point of view, should be selected as the baseline for development by the ISPLS study.

Cryogenic propellant can be transferred from one space vehicle to another by either of the following two general methods or modes : (1) fluid flow mode, the transfer of propellant between elements by some fluid flow technique, and (2) modular mode, the transfer of packaged or contained propellant.

During the initial phase of the ISPLS propellant transfer analysis it was established that the configuration, operational characteristics, and requirements of the space program elements were such as to preclude the modular mode of transfer.

A number of candidate techniques for fluid flow mode in-space transfer of cryogenic propellants has been defined in studies conducted by NASA, NR, and other contractors and agencies. These studies conclude that it is necessary to maintain rigorous control of certain propellant and environmental conditions to achieve effective propellant transfer. These control functions are interrelated and can be categorized in different ways. For the purpose of this study the required control functions have been defined as: (1) liquid/vapor interface control; (2) receiver tank thermodynamic control; (3) liquid expulsion, and (4) net positive suction pressure (NPSP) control.

The selected baseline configuration incorporates separate linear acceleration of the user vehicle/logistic module for liquid/vapor interface control, connected user/logistic module ullage for receiver tank thermodynamic control, gas pump in the ullage return line for liquid expulsion, and an active pressurization system for NPSP control of both propellants.

The system components required to support the fluid transfer operation are incorporated into the logistic module configuration. Concentration of this equipment in the logistic module eliminates the payload penalty associated with transporting component weight on tug payload placement missions, eliminates the need for in-space maintenance of components and eliminates or minimizes the configurational impact upon the user vehicles.

As a result of the analysis conducted, the following general conclusions were formulated:

a. In-space liquid flow cryogenic propellant transfer is feasible for logistic support of all the space program elements considered in the ISPLS study.

b. The order of preference and qualifying constraints for liquid flow propellant transfer are as follows:

    1. Modular - when receiver configuration and operational constraints permit.

    2. Radial Acceleration - when overall center of gravity (c.g.) and operational constraints permit.

    3. Linear Acceleration - requires longer life propulsion system and moderately higher propellant losses.

c. Fluid transfer losses in the range of 0.6% to 5.7% are achievable for fluid flow propellant transfer using acceleration (radial or linear) for liquid/vapor interface control.

d. The fluid flow transfer system configuration is predominantly dependent upon the configuration of the interfacing vehicle.

e. Linear acceleration with the shuttle orbiter detached was selected as the baseline for development by the ISPLS study.

The results of the OPSS study previously conducted by the contractor were used for reference and as a source of quantitative information for the analysis. The OPSS study was also used to formulate some initial guidelines to help direct the propellant analysis effort into the most productive areas of the propellant transfer technology.

As could be expected the general conclusions and guidelines developed from the OPSS results were found to be equally applicable to the ISPLS study. However, when the application was made to the ISPLS study conditions, the emphasis or importance of some of the OPSS considerations changed. This is primarily the result of the configurational and operational differences between a very large space-based propellant storage facility and the smaller orbiter cargo bay size elements such as the space-based tug and the propellant logistic module used for the ISPLS study.

An example of this change in importance will be noted in the consideration of linear acceleration versus radial acceleration for propellant settling or liquid/vapor interface control. During the OPSS study it was determined that the propellant needed to accelerate the depot and settle the propellant using linear thrust was so large that it became very unattractive. Therefore, it was concluded that a radial acceleration technique should be employed for this function. While the analysis conducted for this study also shows that the propellant required for radial acceleration is less than that needed for linear acceleration, the actual quantity of propellant thus saved is no longer an

all-out driving factor. In fact, such factors as configurational complexity and development risk were judged to outweigh the propellant savings to the extent that linear thrust was selected as the baseline method for propellant settling for all in-space propellant transfer operations of this study.

Another interesting development of this more rigorous evaluation of the linear acceleration concept is the orbital mechanics of cross-plane technique of thrusting. As a result of this analysis it was learned that ideally continuous cross plane thrusting perpendicular to the initial orbit plane will produce an orbital path which will return to the initial orbit once each revolution. Under the ideal conditions no distance, inclination, or velocity deltas exist at this point of coincidence. When earth oblateness effects were introduced into the computer analysis conducted, it was determined that a small but increasing distance delta occurred after each orbit. This delta is approximately one quarter of a nautical mile after the first orbit, and when extrapolated to the 10-orbit (15 hours) condition of propellant transfer the separation was approximately seven nautical miles.

6.1 TRANSFER CONCEPT ANALYSIS

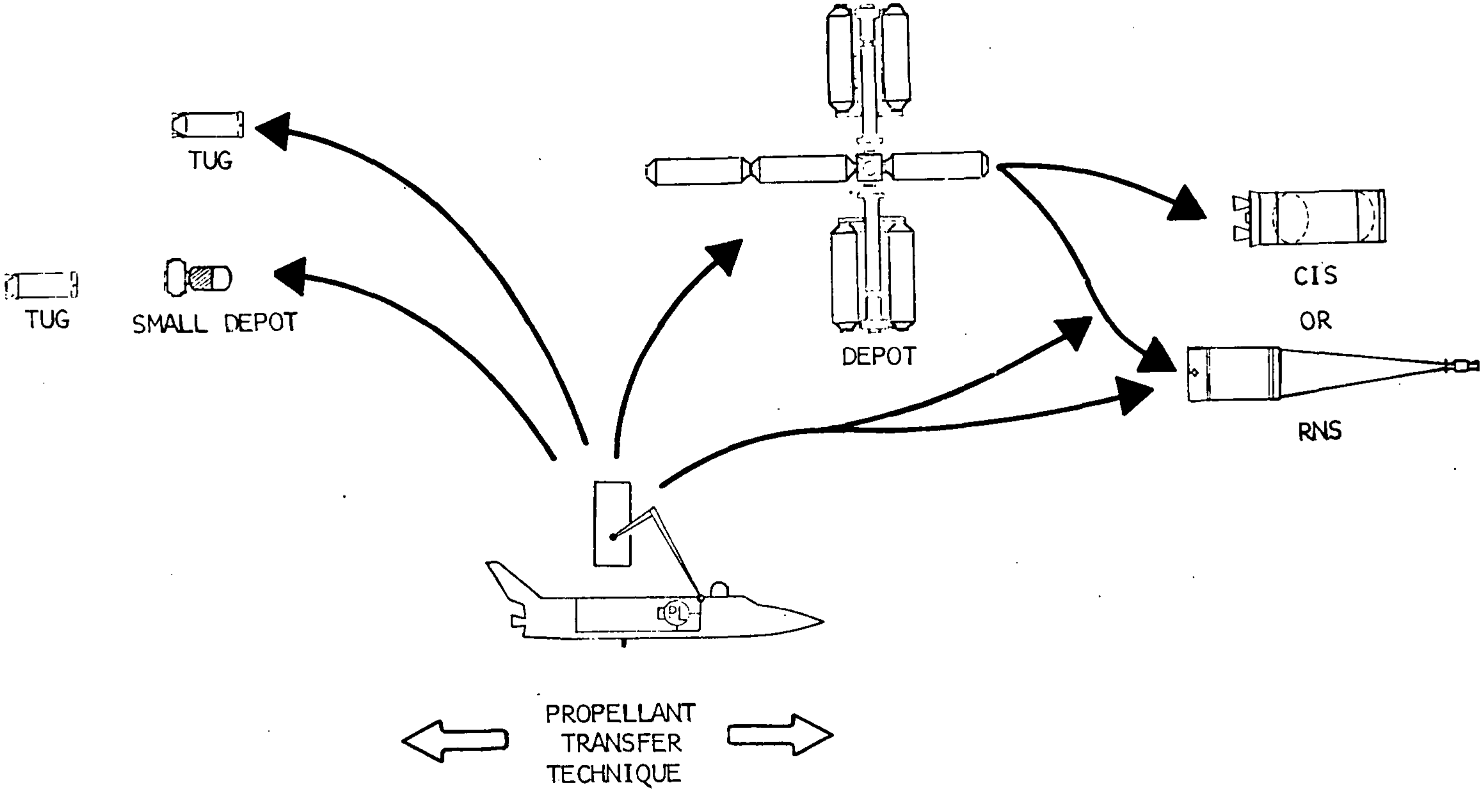
The primary propellant transfer interfaces considered by the study are depicted on Figure 6.1-1. Two major transfer options must be considered for transfer of propellant between the various ISPLS space elements: (1) modular transfer, the transfer of packaged or contained propellant as a unit, and (2) fluid flow transfer. Modular transfer results in minimum propellant transfer loss and is first preference when the receiver element is suited to this technique. The fluid flow transfer technique, which has more rigorous functional and operational interface requirements and results in significant propellant transfer loss, must be used when the receiver element configuration is incompatible with the modular technique.

The performance and functional characteristics of the fluid flow propellant transfer techniques are dependent on the complete liquid flow system. Therefore, the following analysis is based upon system concepts consisting of the propellant tanks, interfacing hardware and all of the fluid flow transfer and control equipment of both user and supplier vehicle.

The functions required to transfer cryogenic propellant by a liquid flow technique have been identified. For the purposes of this analysis these interrelated functions have been classified and defined as follows. An acceptable system must provide the capability and control necessary to accomplish all functions:

a. Provide adequate liquid/vapor interface control to insure acceptable supplier tank outflow, liquid phase or acceptable quality flow through the transfer lines, and acceptable receiver inflow conditions.

b. Provide receiver tank thermodynamic control as required to insure acceptable inflow characteristics, prevent propellant loss due to unnecessary or uncontrolled overboard venting of liquid or vapor, and to produce propellant temperature and pressure conditions which



MODULAR

- NO PROPELLANT LOSS
- DEPENDENT ON RECEIVER CONFIGURATION

FLUID

- SIGNIFICANT PROPELLANT LOSS
- COMPATIBLE WITH USER VEHICLE CONFIGURATIONS

Figure 6.1-1 In-Space Propellant Transfer Interfaces

fulfill the receiver vehicle's propulsion system or outflow requirements.

c. Provide the energy and/or means of expelling the propellant from the supplier into the receiver.

d. Provide NPSP control (vapor pressure control) as required to establish subcooled or acceptable quality propellants to meet the requirements as established by the total propellant transfer system.

Conceptual sketches of techniques for control of each of the above functions are shown on Figure 6.1-2. The more promising of these concepts have been identified and utilized in the concept trade analysis. The results of these trade studies are presented in Section 6.0 of Volume III.

Since the supplier configuration can be designed to meet the requirements of the receiver and the transfer operation as a whole, the problem becomes primarily one of compatibility between the supplier/receiver configurations and the particular transfer technique to be employed. Because the receiver is also a propellant user vehicle, in most cases, and must be designed to fulfill its primary mission requirements, it is the most constrained and may become the driver in the selection of the configuration and technique to be used for the particular transfer operation.

The following summary is an example of the factors which must be considered to establish the relative merits of the transfer concepts and to identify the best baseline configuration and operational concept.

Propellant Liquid/Vapor Interface Control

In general, for configurations utilizing radial acceleration to provide the liquid/vapor interface control, the combined system (supplier, receiver, and any interfacing devices which may be employed) must maintain its axis of rotation (c.g.) between the tanks (outside) of the supplier and receiver vehicles or as an alternate, some method of liquid/vapor separation must be provided. Other alternatives include stand pipes for venting a centrally located ullage or the use of a thermodynamic vent system to allow efficient venting of liquid. Thrusting devices and a control system to accelerate, decelerate, and maintain dynamic stability during the transfer operation will be required.

For linear acceleration, and assuming that guidance and control functions are needed by the receiver to support its primary mission, the primary impact will be the linear acceleration thrusters and the additional propellant which may be consumed by the application of this technique. Capillary devices installed in the propellant tanks may constrain or limit other operations such as filling, liquid level gauging, dynamic load capability, or system resistance to damage from two-phase flow or flow surges.

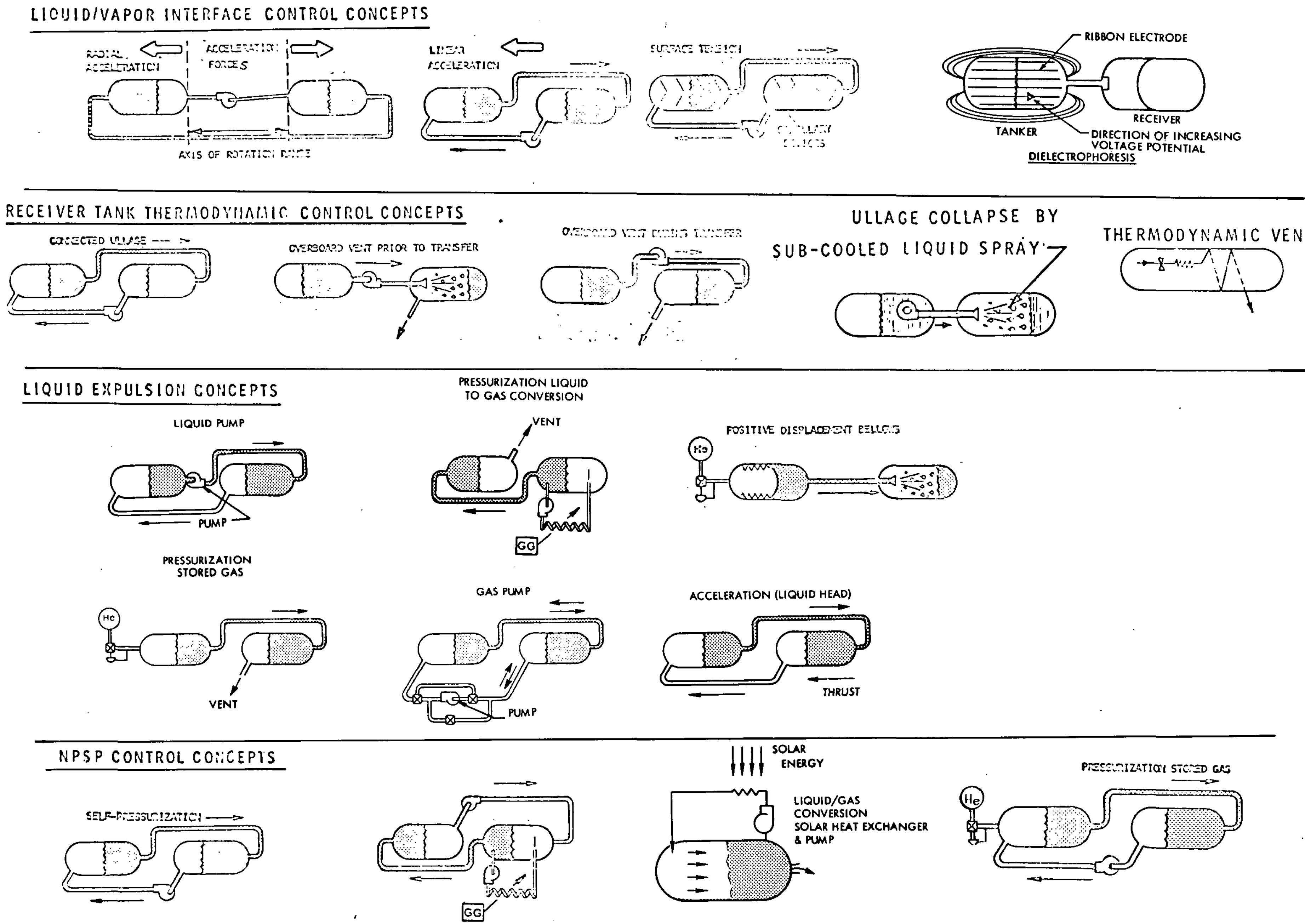


Figure 6.1-2 Transfer Techniques

Receiver Tank Thermodynamic Control

The principal impact of this requirement will be to dictate that the interfaces provide for a vapor return system if a system utilizing connected ullages is selected. If overboard venting is utilized, a nonpropulsive vent system may be required to reduce the guidance and control problem. The system must prevent propellant loss by unnecessary or uncontrolled venting of liquid or vapor.

Liquid Expulsion

Pumping systems and their support equipment should be installed on the supplier vehicle in order to reduce the weight of the receiver vehicle since its performance is more weight sensitive. If a liquid pump system is selected, it may be necessary to provide submerged type pumps in both supplier and receiver tanks to provide reversible flow capability for safety considerations. Submerged liquid pumps are desirable to provide the necessary NPSP to prevent pump cavitation and two-phase or flow breakdown. Gas pumps are more adaptable to line installation and thus provide an advantage in terms of accessibility.

As stated above, when possible the transfer systems should be installed on the supplier to minimize the weight of the receiver. Therefore, the impact for selection of a pressurization system for liquid expulsion would predominantly influence the supplier configuration by the addition of a stored gas or liquid-to-vapor conversion system.

Net Positive Suction Pressure (NPSP) Control

Propellant transfer accomplished by pumping fluid between the tanks will require control of the NPSP. The ullage pressure must be maintained above the vapor pressure with sufficient margin to prevent boiling and two-phase flow in the transfer lines and receiver tank inlet. Alternately, the complete system could be designed for mixed phase flow. Mixed phase conditions in the transfer lines and tanks could be expected with a self-pressurization concept. An active pressurization system can be designed to provide the margin required to insure liquid phase transfer.

In summary, the following criteria were used to select the technicallv preferred approach for each of the propellant transfer operations discussed above:

a. Technical feasibility

b. Propellant transfer losses

c. Compatibility with user and logistic vehicle systems

d. Development risk

e. Safety

6.1.1 Liquid/Vapor Interface Control

As indicated by Figure 6.1.1-1, the concepts evaluated employed either acceleration or surface tension as the mechanism for the liquid/vapor interface control. Figure 6.1.1-2 presents the data used to relate the logistic tank propellant residuals with the jet propellant (the propellant consumed to provide constant linear acceleration). The minimum loss transfer time for an acceleration factor of 10^{-5} g was determined to be approximately 80 hours. In order to reduce this time to a more practical value the factors were determined for an acceleration of 10^{-4} g. The total loss curve for the 10^{-5} g condition is shown for reference. This evaluation indicates that the minimum propellant loss associated with residuals and jet propellant for the 10^{-4} g condition is approximately 1.9 percent of the transferred propellant (60K pounds) at a transfer time of approximately 10 hours. An investigation of the drawdown characteristics of various tank bottom configurations was conducted to establish representative propellant tank residuals. Figure 6.1.1-3 summarizes the results of this analysis.

The linear acceleration technique requires constant thrust application for the full duration of the transfer with the transfer losses primarily a direct function of time and an inverse function of acceleration factor. Conversely, the radial technique requires thrust for spin-up and spin-down only; the propellant transfer is accomplished with the system free spinning. Therefore, the propellant transfer losses are primarily a function of acceleration factor and are relatively insensitive to transfer time. Figure 6.1.1-4 presents the propellant loss characteristics of a logistic-tank-to-tug radial acceleration system as a function of acceleration factor. The orbiter was used as a counterweight to prevent migration of the center of rotation beyond acceptable limits. A 10-hour transfer time was used to provide a meaningful comparison with the characteristics of the linear system; 5-hour and 20-hour total loss points have been included to indicate the time sensitivity of the system. The minimum propellant loss for a 10-hour transfer is 0.35 percent of the transferred propellant (60K pounds) at an acceleration factor of approximately 10^{-3} g.

An important consideration in the evaluation of rotational propellant transfer is the center of gravity (c.g.) location and migration during the transfer operation. Successful transfer of propellants using centrifugal forces to orient and settle the propellant depends on maintaining a favorable location of propellants relative to the axis of rotation which is determined by the c.g. From the standpoint of ullage venting, the most desirable location for the c.g. is outside the propellant tanks so that the relative position of the liquid and ullage location remains essentially fixed. This required separating the logistic module and the receiver vehicle by a rigid boom to distribute the vehicle masses so that, whether loaded or empty, the c.g. of the configuration will always fall between the two vehicles. However, when the weight differential between the logistic module and receiver vehicle is large (e.g., a loaded CIS and logistic module), the length of the boom becomes prohibitively long.

Transfer of propellants in the rotational mode without the use of a transfer boom was investigated for CIS. Two configurations were studied. One configuration consisted of only the CIS and logistic module (shuttle detached),

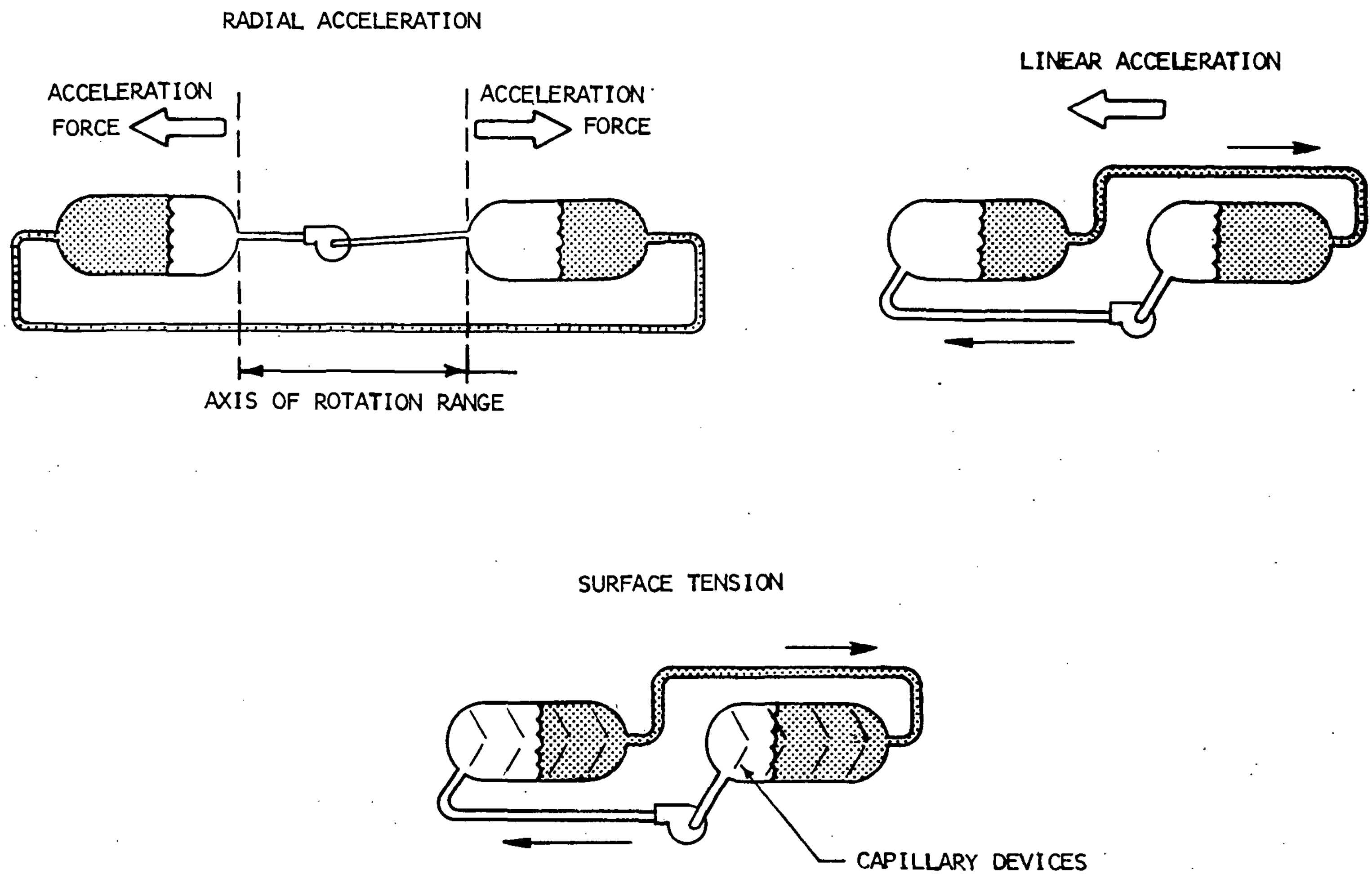


Figure 6.1.1-1 Candidate Liquid/Vapor Interface Control Concepts

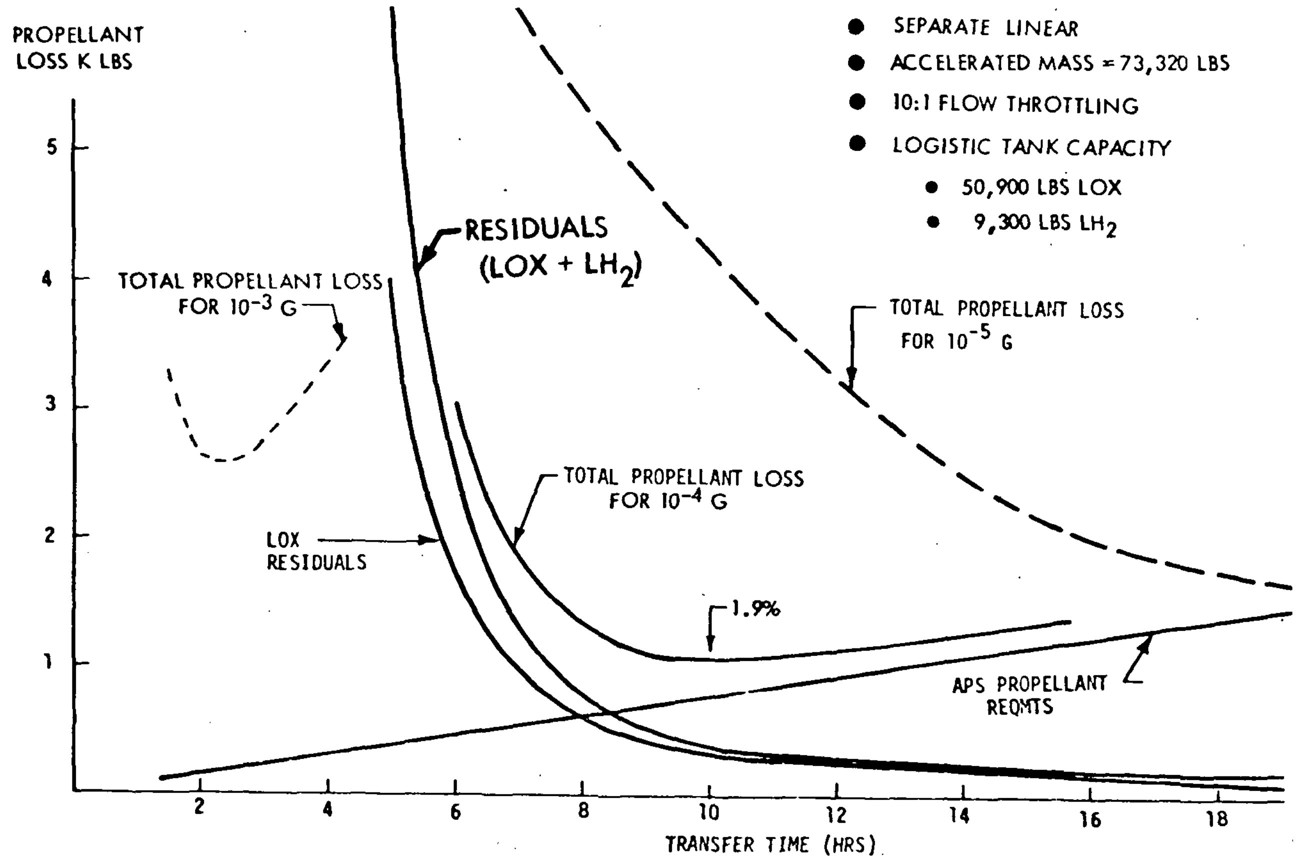
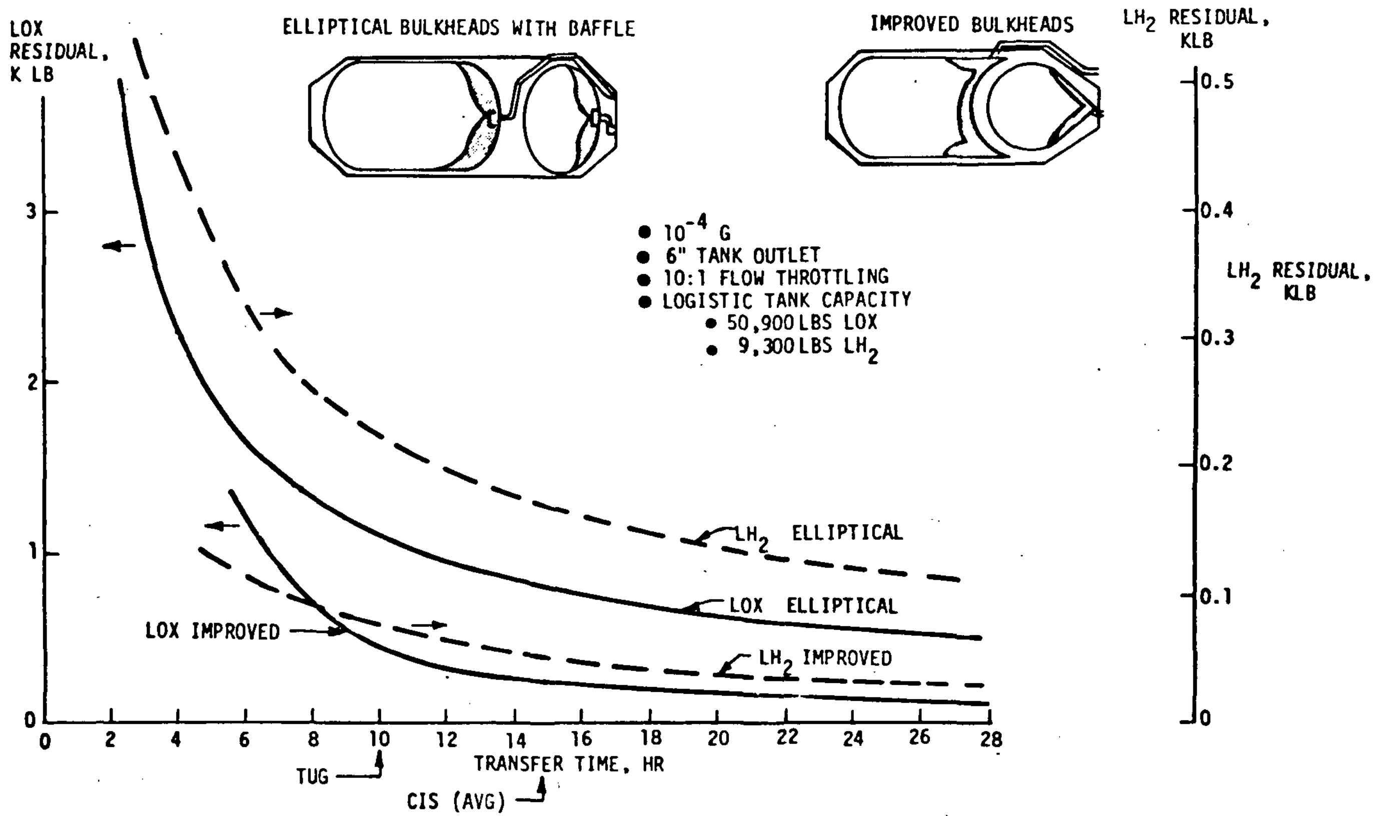
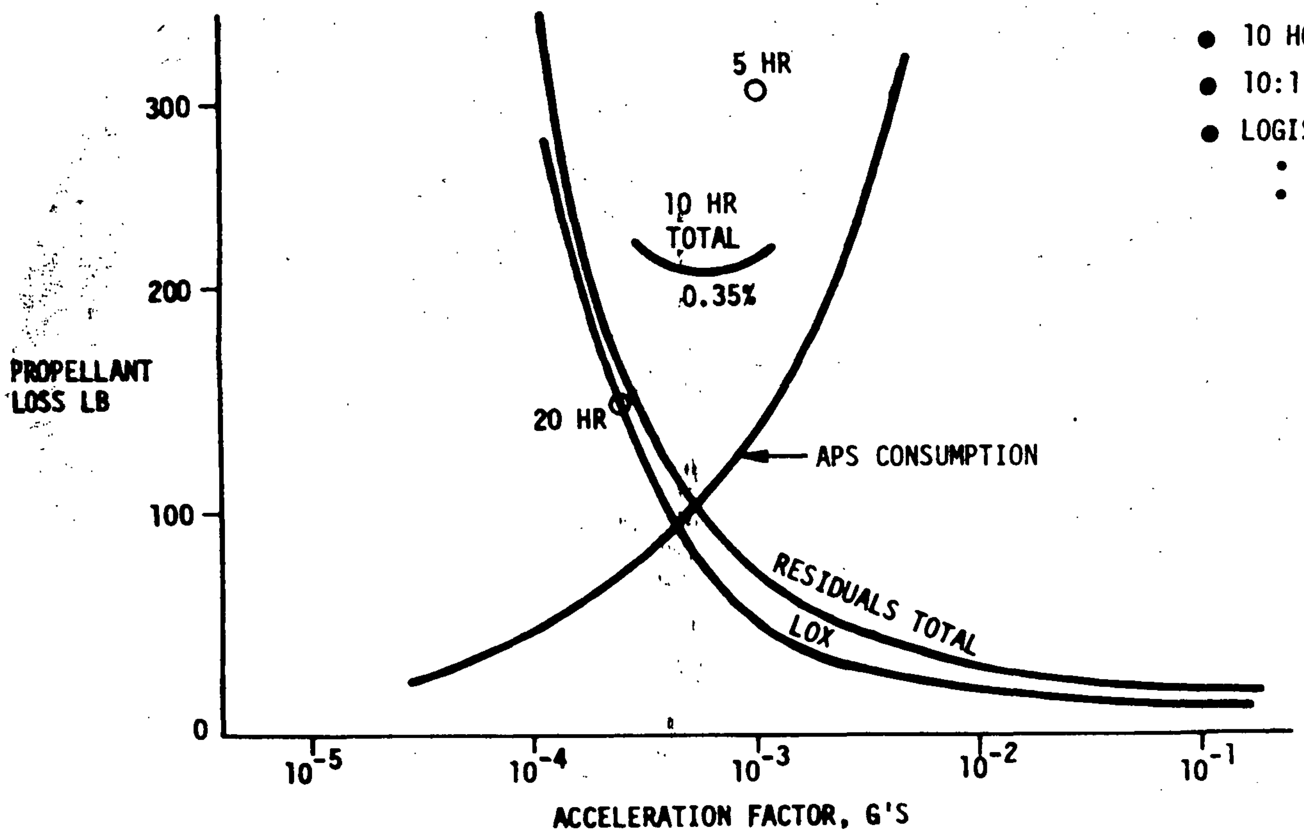


Figure 6.1.1-2 Linear Acceleration Propellant Losses Direct Transfer to S.B. Tug



● **CONICAL LOX BULKHEAD PROVIDES SIGNIFICANT WEIGHT SAVINGS (700 LBS)**

Figure 6.1.1-3 Influence of Tank Geometry on Liquid Residuals



- DEPLOYED ROTATION
- 10 HOUR TRANSFER TIME
- 10:1 FLOW THROTTLING
- LOGISTIC TANK CAPACITY
  - 50,900 LBS LOX
  - 9,300 LBS LH_2

- ROTATION MORE EFFICIENT THAN LINEAR
- LOSSES FOR ROTATION LESS SENSITIVE TO TRANSFER TIME

Figure 6.1.1-4 Rotational Transfer Propellant Losses Direct Transfer to S.B. Tug

and another consisted of the CIS and logistic module with the shuttle attached as a counterweight. For each of the configurations, calculations were made of c.g. locations and liquid levels as functions of the number of propellant loads transferred to the CIS. The c.g. locations and liquid levels were determined for conditions just prior to initiating propellant transfer and after completion of transfer for each load transferred.

The c.g. locations and liquid levels as functions of the number of logistic module propellant loads transferred to the CIS stage for a deployed rotational mode are shown in Figure 6.1.1-5. The LH_2 tank is filled at the tank bottom for the first five propellant tank loads transferred, and from the top of the tank for the remaining. The LH_2 ullage shifts from the forward end of the tank to a position within the bulk liquid. This requires an additional vent outlet besides that provided for flight operational requirements. The LO_2 tank ullage remains located at the forward end of the tank throughout the entire propellant transfer operation.

The advantages of both modes of transfer, besides lower propellant losses mentioned previously, is that perturbations to the parking orbit which may require corrective maneuvers are reduced since thrusting is required only during spin up and despin maneuvers and not continuously as required for the linear propellant transfer mode. Separate rotational transfer offers an advantage in that the shuttle can be used for other purposes during the propellant transfer period. An advantage of the deployed rotational mode is that one docking maneuver is eliminated since the logistic module remains attached to the shuttle.

The requirement for providing additional CIS propellant tank fill inlets and vent outlets to satisfy all phases of operations (ground fill, in orbit transfer, and flight) adds to the complexity of the propellant feed and ullage vent systems. The position stability of the ullage once it detaches from the tank wall (near full conditions) may be poor so that the placement of vent outlets in order to satisfy adequate ullage venting can become a major design problem. Another disadvantage of the rotational propellant transfer mode is that, if discrete liquid level sensing gauging systems are used (i.e., capacitance probe and point sensors), gauging measurements are non-linear.

Figure 6.1.1-6 shows a concept for liquid/vapor interface control by rotation about the longitudinal or minor axis of the system. For the vehicle configurations considered, this technique is unattractive due primarily to its inherently poor outflow characteristics which result in high propellant residuals.

A promising alternative to linear or radial acceleration is the use of capillary devices for liquid/vapor interface control. A schematic of a capillary system to effect transfer of propellant from the logistic module to the CIS is shown in Figure 6.1.1-7. This capillary system consists of capillary collector tubes in the logistic module tanks for propellant acquisition from any region of the tanks. The CIS requires fill and vapor/liquid interface control baffles to permit orderly filling and vapor return to the source tanks.

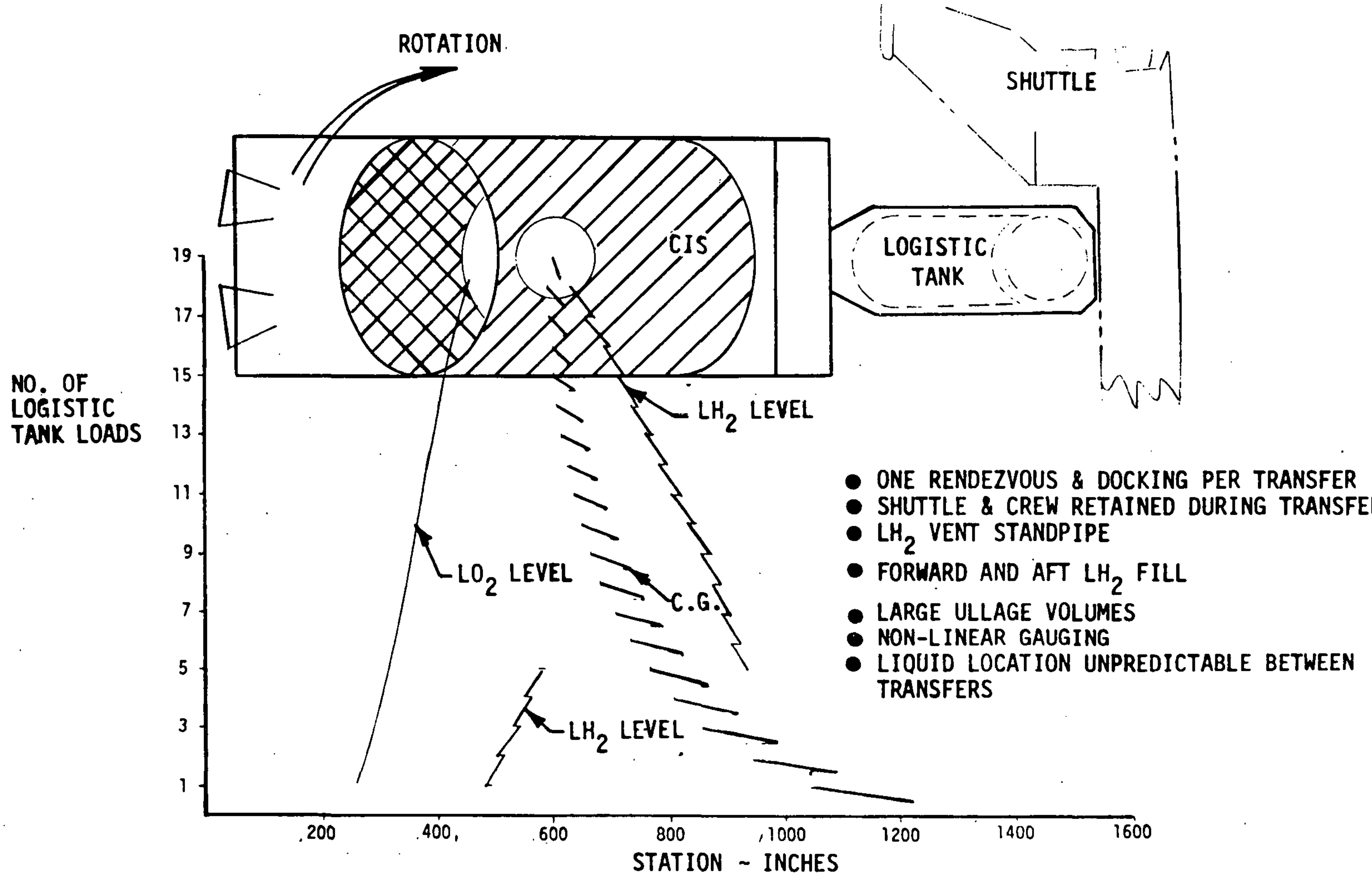


Figure 6.1.1-5 Deployed Rotation Direct Transfer to CIS

ADVANTAGE

- BOOM NOT REQUIRED FOR CG CONTROL

DISADVANTAGES

- HIGH LIQUID RESIDUALS
- POOR LIQUID CONFIGURATION STABILITY
- POOR VEHICLE ROTATIONAL STABILITY
- CONFIGURATIONAL COMPLEXITY

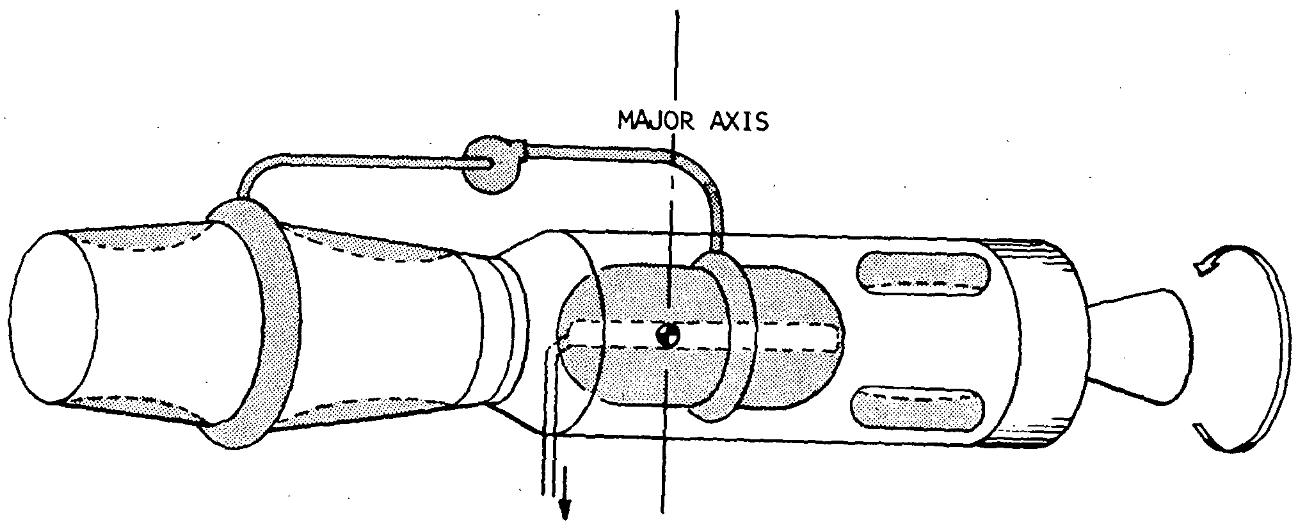
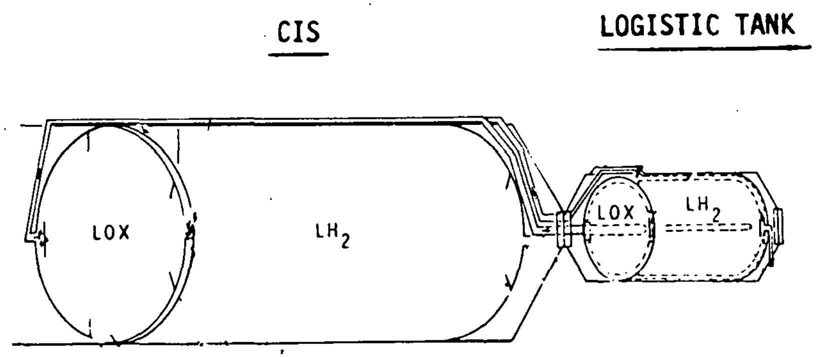


Figure 6.1.1-6 Radial Acceleration Spin

Space Division
North American Rockwell



- CAPILLARY DEVICES REQUIRED IN BOTH SOURCE & RECEIVER TANKS
- SUBCOOLED PROPELLANTS REQUIRED
  - THERMAL CONTROL SYSTEM INTEGRATED WITH CAPILLARY DEVICES
- SHUTTLE MAY OR MAY NOT REMAIN ATTACHED
- EXISTING USER VEHICLE APS USED FOR:
  - INITIAL SETTLING
  - INTERMITTENTLY AS REQUIRED TO AVOID LIQUID VENTING
  - GAUGING

Figure 6.1.1-7 Capillary Direct Transfer to CIS

Space Division
North American Rockwell

These hardware provisions permit reduction of thrusting requirements; however, thrusting is still required for gauging, for initial settling, and at times during transfer to reposition dislocated propellant. Thrusting may also be required continuously during the last few transfers because of the difficulty of obtaining propellant-free vapor return from the nearly full receiver tank.

This approach reduces the thrusting and maneuvering requirements and decreases jet propellant consumption. It may be possible to utilize the existing auxiliary propulsion system on the CIS. Because of the network of collector tubes along the perimeter of the logistic tank, residuals are less sensitive to sloshing. Another advantage of using this quasi-passive method of transfer is the compatibility of this approach with a wide range of receiver configurations, i.e., center of mass location is not as important if only limited maneuvers are involved.

Of course, use of capillary devices introduces additional hardware complexity and development risk. Problems associated with such devices are identified in the Supporting Research & Technology section of Volume IV.

A comprehensive analysis was conducted to evaluate various methods for providing the acceleration force to control the liquid/vapor interface. The configurations studied included: (1) separate linear acceleration of the propellant logistic module and each of the three primary ISPLS user vehicles, (2) linear acceleration of the tug/propellant module and attached orbiter, (3) rotation of the CIS and tug using the orbiter as a counterweight, (4) the use of booms or mini-depot arrangements to provide the necessary c.g. control for rotation, and (5) the use of intermittent thrusting in conjunction with capillary devices. These configurations are schematically portrayed in Figures 6.1.1-8 and 6.1.1-9 for the tug and CIS, respectively. Tables 6.1.1-1 and 6.1.1-2 summarize the advantages and disadvantages identified for each of these candidate propellant transfer configurations. It should be noted that the CIS concepts for rotational and capillary liquid/vapor interface control were evaluated on the basis that the existing CIS thermodynamic vent system would be used for receiver tank thermodynamic control. As discussed in Section 6.1.2, use of this system negates the requirement for positive liquid/vapor interface control in the receiver tank. As a result of this analysis, separate linear acceleration of the logistic module and user vehicle was selected as the baseline technique for all ISPLS liquid flow transfer operations. In making this selection, it was concluded that no major selection drivers could be identified and that the configuration and operational complexity and the development risk factors outweigh the lower propellant loss of the other concepts. A complete discussion of the results of this study are presented in Section 6.0 of Volume III.

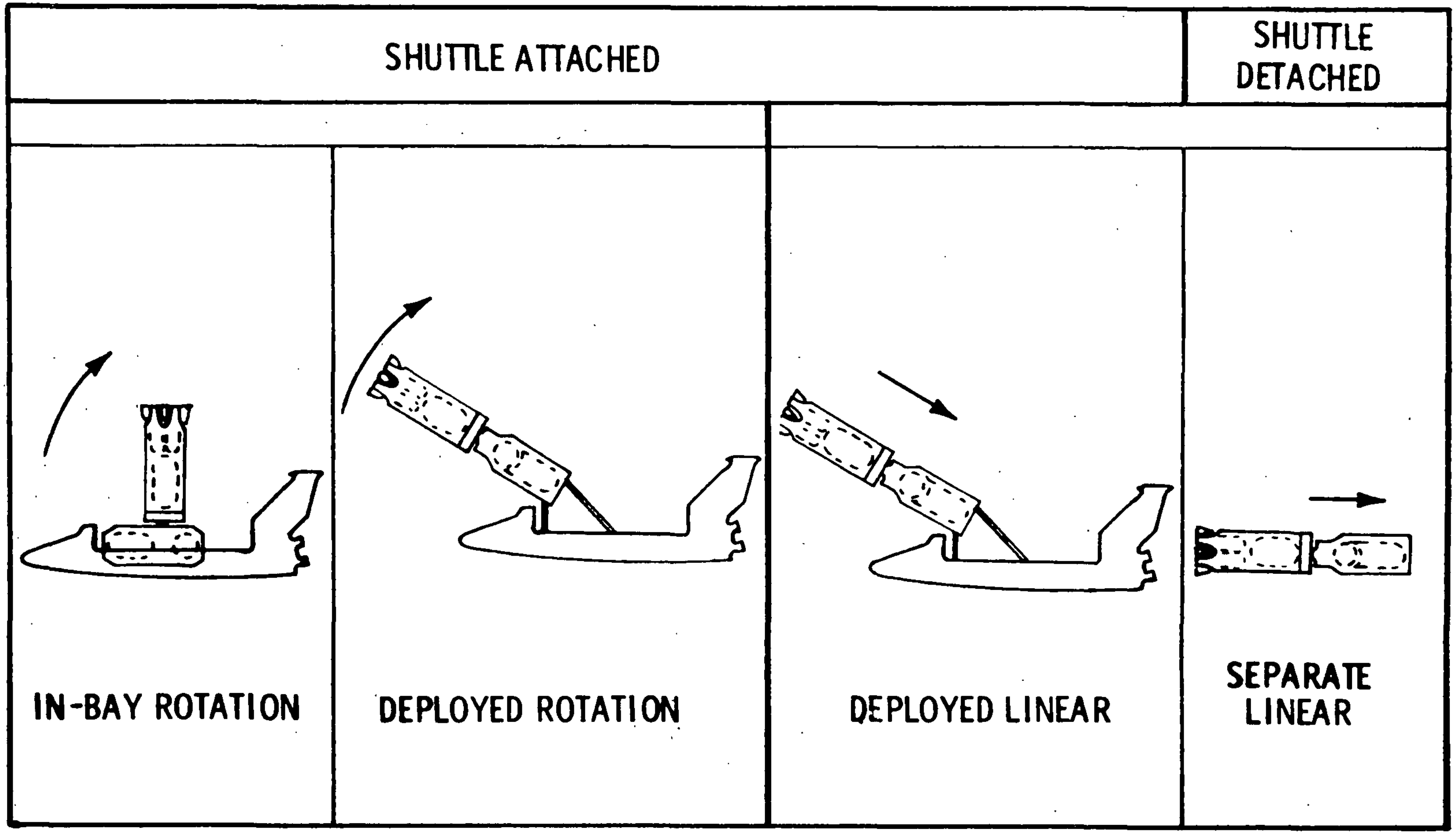


Figure 6.1.1-8 Alternate Concepts for Direct Transfer to S.B. Tug

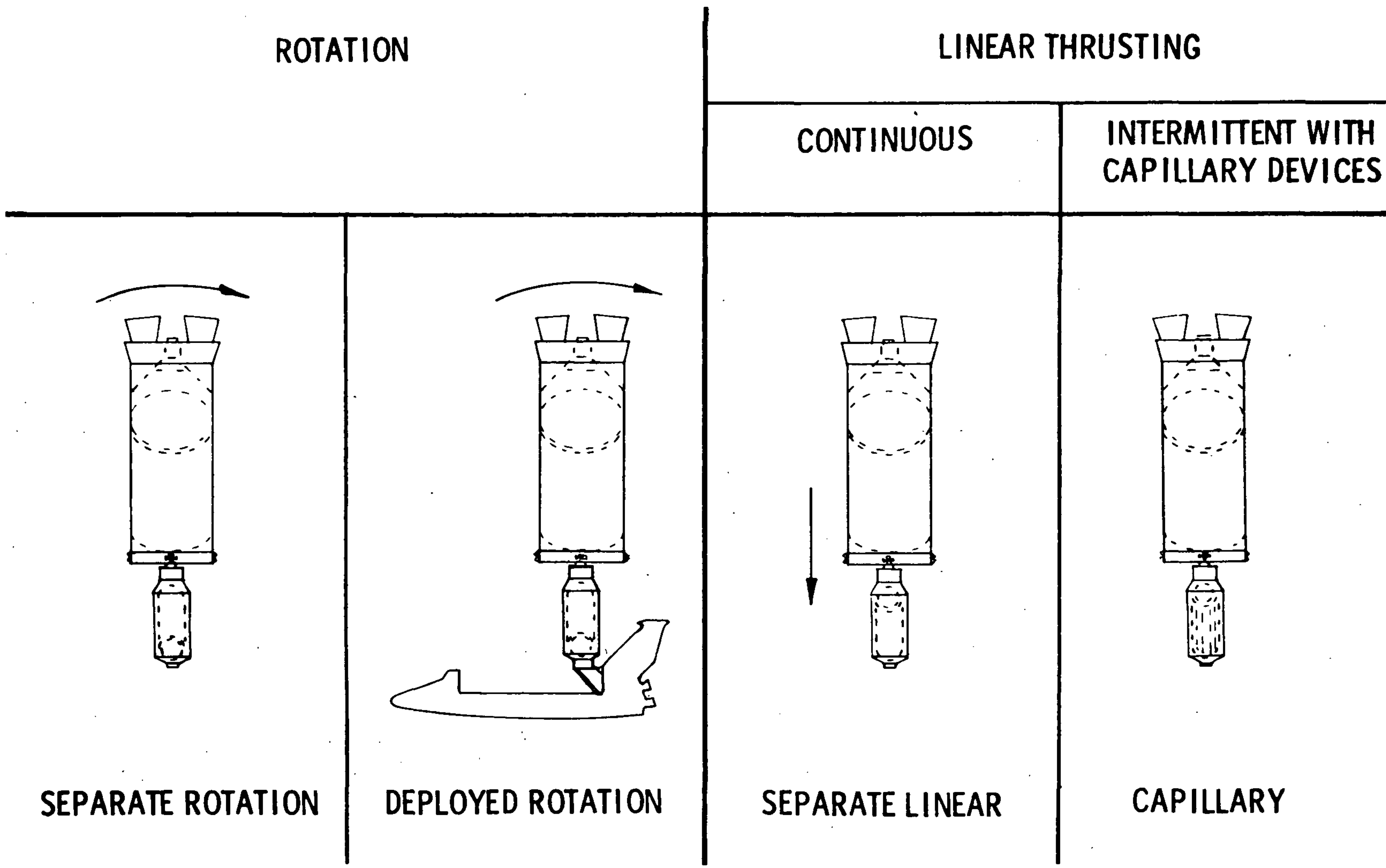


Figure 6.1.1-9 Alternate Concepts for Direct Transfer to CIS

	ADVANTAGES	DISADVANTAGES
IN-BAY ROTATION	● NO DEPLOYMENT OF TANK ● ONE RENDEZVOUS & DOCKING PER TRANSFER ● LOW PROPELLANT LOSSES ● COMPATIBLE WITH CURRENT MANIPULATOR ARMS	* ● SIDE TANK VENTING OF TUG * ● NON-LINEAR GAUGING ● INVERTED GROUND FILL & VENT * ● SHUTTLE & CREW RETAINED DURING TRANSFER
DEPLOYED ROTATION	● STANDARD TUG FILL & VENT LOCATION ● LINEAR GAUGING ● ONE RENDEZVOUS & DOCKING PER TRANSFER ● LOW PROPELLANT LOSSES	● FLEXIBLE PROPELLANT LINE INTERFACE ● COMPLEX DEPLOYMENT & SUPPORT * ● SHUTTLE & CREW RETAINED DURING TRANSFER ● LONGER MANIPULATOR ARMS
DEPLOYED LINEAR	● STANDARD TUG FILL & VENT LOCATION ● LINEAR GAUGING ● ONE RENDEZVOUS & DOCKING PER TRANSFER	* ● HIGH PROPELLANT LOSSES ● FLEXIBLE PROPELLANT LINE INTERFACE ● COMPLEX DEPLOYMENT & SUPPORT * ● SHUTTLE & CREW RETAINED DURING TRANSFER ● LONGER MANIPULATOR ARMS
SEPARATE LINEAR	● STANDARD TUG FILL & VENT LOCATION ● LINEAR GAUGING * ● INDEPENDENT DEPLOYMENT & TRANSFER CONCEPTS * ● SHUTTLE & CREW FREE DURING TRANSFER	● MODERATE PROPELLANT LOSSES ● FLUID INTERFACE DISCONNECTS ● TWO RENDEZVOUS & DOCKING PER TRANSFER

- NO MAJOR SELECTION DRIVER IDENTIFIED
  - ALL CONCEPTS VIABLE
- SEPARATE LINEAR USED FOR FURTHER STUDY
  - BASED PRIMARILY ON * CONSIDERATIONS

Table 6.1.1-1 Concept Comparisons for Direct Transfer to S.B. Tug

	ADVANTAGES	DISADVANTAGES
SEPARATE ROTATION WITH THERMODYNAMIC VENTING	• LOW PROPELLANT LOSSES • SHUTTLE & CREW FREE DURING TRANSFER	* • NON-LINEAR GAUGING * • BULK LIQUID MIXERS • IMPACT ON THERMODYNAMIC VENT SYSTEM • INCREASED DEVELOPMENT RISK
DEPLOYED ROTATION WITH THERMODYNAMIC VENTING	• ONE RENDEZVOUS & DOCKING PER TRANSFER • LOW PROPELLANT LOSSES	* • NON-LINEAR GAUGING • SHUTTLE & CREW RETAINED DURING TRANSFER * • BULK LIQUID MIXERS • IMPACT ON USER THERMODYNAMIC VENT SYSTEM • INCREASED DEVELOPMENT RISK
SEPARATE LINEAR WITH GAS RETURN TO SOURCE TANK ✓	* • LINEAR PROPELLANT GAUGING * • NO IMPACT ON USER THERMODYNAMIC VENT SYSTEM • BULK LIQUID MIXERS NOT REQUIRED • MINIMUM DEVELOPMENT RISK	• MODERATELY HIGH PROPELLANT LOSSES • TWO RENDEZVOUS & DOCKINGS PER TRANSFER • VARIABLE ACCELERATION LEVELS & TRANSFER TIMES
CAPILLARY WITH THERMODYNAMIC VENTING	• REDUCED PROPELLANT LOSSES • APS NOT REQUIRED ON LOGISTIC TANK • SHUTTLE MAY OR MAY NOT REMAIN	• INTERNAL TANK HARDWARE COMPLEXITY * • INTEGRATION WITH THERMAL CONTROL • IMPACT ON USER THERMODYNAMIC VENT SYSTEM * • INCREASED DEVELOPMENT RISK

- **SEPARATE LINEAR CHOSEN FOR ISPLS BASELINE**
  - **BASED PRIMARILY ON * CONSIDERATIONS**

Table 6.1.1-2 Concept Comparisons for Direct Transfer to CIS

Propellant transfer losses based on a 10-hour transfer time for the logistic module to the tug and computed in percentage of the 60,000 pound propellant load are summarized in Table 6.1.1-3. This data shows the major losses to the APS propellant and liquid residuals, the propellant required for net positive suction pressure (NPSP) control, and other purposes being small and insensitive to transfer method. For the rotational methods, the acceleration level was chosen to minimize propellant losses. For the linear acceleration methods, 10^{-4}g proved the most practical acceleration level. The rotational methods entailed lower propellant losses than the linear methods because of the small APS propellant requirements and reduced residuals.

APS propellant requirements are substantially lower for the separate linear method than for the deployed linear method, because of the space shuttle mass which must be accelerated for the deployed linear method.

A breakdown of logistic program costs for the tug supportive missions are presented in Figure 6.1.1-10. Program costs are based on the program C level, Logistic Concept 2, employing the separate linear acceleration transfer configuration. Shuttle flight and hardware cost elements, and the relative magnitude of the costs to each other are indicated.

A comparison of the cost of propellant transfer losses and the percentage of the total program cost that the losses represent is made for the various propellant transfer configurations. As shown, the cost of the transfer losses for all the configurations is small when compared to total program costs. Therefore, it is concluded that the program costs are relatively insensitive to the transfer configuration and factors other than cost are the major drivers which influence the transfer configuration selection.

The four alternate methods for propellant transfer to the CIS are compared on the basis of propellant transfer losses on Table 6.1.1-4. A transfer time of 15 hours was used for each case, as representing an overall average. Losses associated with pressure control were, as in the case of the tug, insensitive to the transfer method, but, unlike the tug, these losses were not insignificant. However, APS propellant and liquid residuals were still the key determinants of transfer efficiency.

For the rotational methods the acceleration level was chosen to minimize APS propellant and liquid residual losses. For both separate and deployed rotation the losses were about the same. For the separate linear method, as thrust was constant, the acceleration level varied with propellant loaded. Losses are averaged over the different transfers. These losses were appreciably greater than those for the rotational methods. The large APS propellant requirements associated with the separate linear method may be substantially reduced by utilization of capillary devices. The capillary method reduced liquid residuals by about 30 percent, compared to the separate linear method. These improvements placed the use of capillary devices between the rotational and the separate linear methods in respect to propellant losses.

A breakdown of logistic program costs for the CIS supportive missions for Program Level D using separate linear propellant transfer is shown in Figure 6.1.1-11. Hardware and shuttle flight costs and their relative magnitudes

Table 6.1.1-3 Comparative Propellant Transfer Losses for Direct Transfer to S.B. Tug

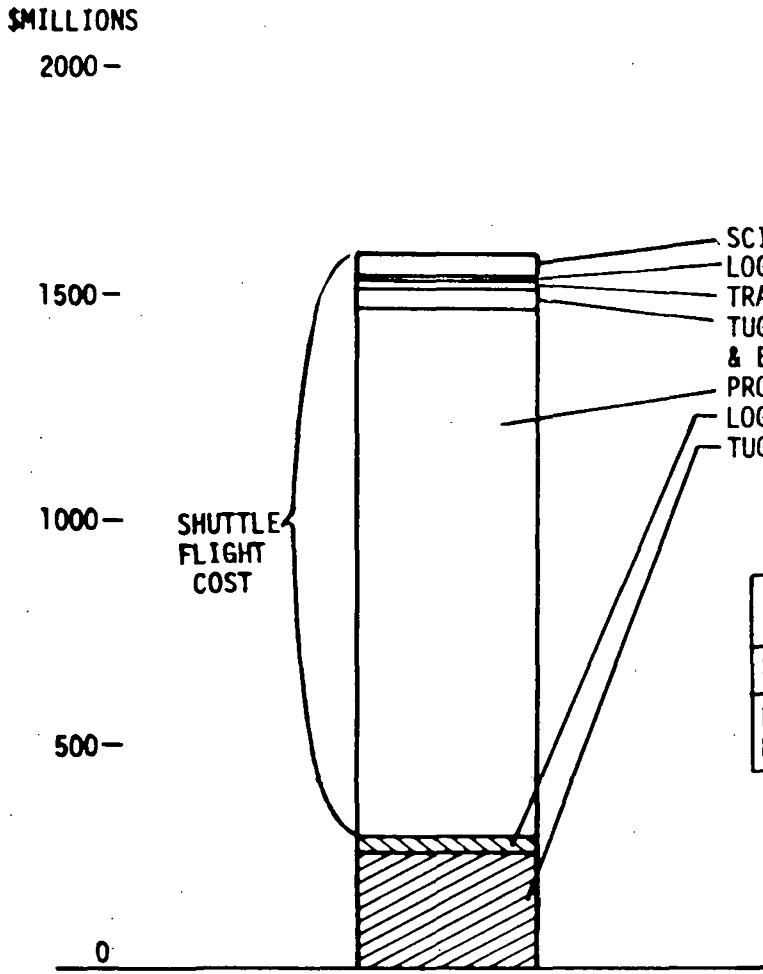
- BASED ON 10 HRS TRANSFER TIME
- LOSSES IN % OF 60 KLBS

CONFIGURATION	IN-BAY ROTATION	DEPLOYED ROTATION	DEPLOYED LINEAR	SEPARATE LINEAR
ACCELERATION, G'S	$2x10^{-3}$	$8x10^{-4}$	10^{-4}	10^{-4}
APS PROPELLANT	0.2	0.2	4.2	1.3
LIQUID RESIDUALS	0.2	0.2	0.6	0.6
NPSP CONTROL	0.1	0.1	0.1	0.1
OTHER*	0.1	0.1	0.1	0.1
TOTAL	0.6	0.6	5.0	2.1

*PUMPING POWER, LINE RESIDUALS, LINE CHILLDOWN, AND HEAT LEAK

- TRANSFER EFFICIENCY DRIVEN BY APS PROPELLANT AND RESIDUALS
- ROTATION MORE EFFICIENT THAN LINEAR
- SEPARATE LINEAR MORE EFFICIENT THAN DEPLOYED LINEAR

- PROGRAM LEVEL C, LOGISTIC CONCEPT 2
- 1985-1990
- 0-30 DEGREE INCLINATIONS



	$
SCIENTIFIC PAYLOAD TRANSPORT	44M
LOGISTIC TANK BOILOFF	2M
TRANSFER LOSSES	27M
TUG ORBITAL MAINTENANCE & BOILOFF LOSSES	32M
PROPELLANT USED BY TUG*	1175M
LOGISTIC TANK COST	37M
TUG COSTS (PROD. & OPS)	251M
TOTAL	1568M

COST OF TRANSFER LOSSES

CONFIGURATION	IN-BAY ROTATION	DEPLOYED ROTATION	DEPLOYED LINEAR	SEPARATE LINEAR
$ MILLION	6.4	6.4	32.2	27.0
PERCENT OF TOTAL PROGRAM COST	0.4	0.4	2.1	1.7

*INCLUDES TANK TRANSPORT - $96M
EXTRA TUG TRANSPORT - $16M

- LOSSES ARE SMALL PERCENTAGE OF PROGRAM COST
- COSTS ARE RELATIVELY INSENSITIVE TO TRANSFER CONCEPT

Figure 6.1.1-10 Logistic Program Costs for Direct Transfer to S.B. Tug

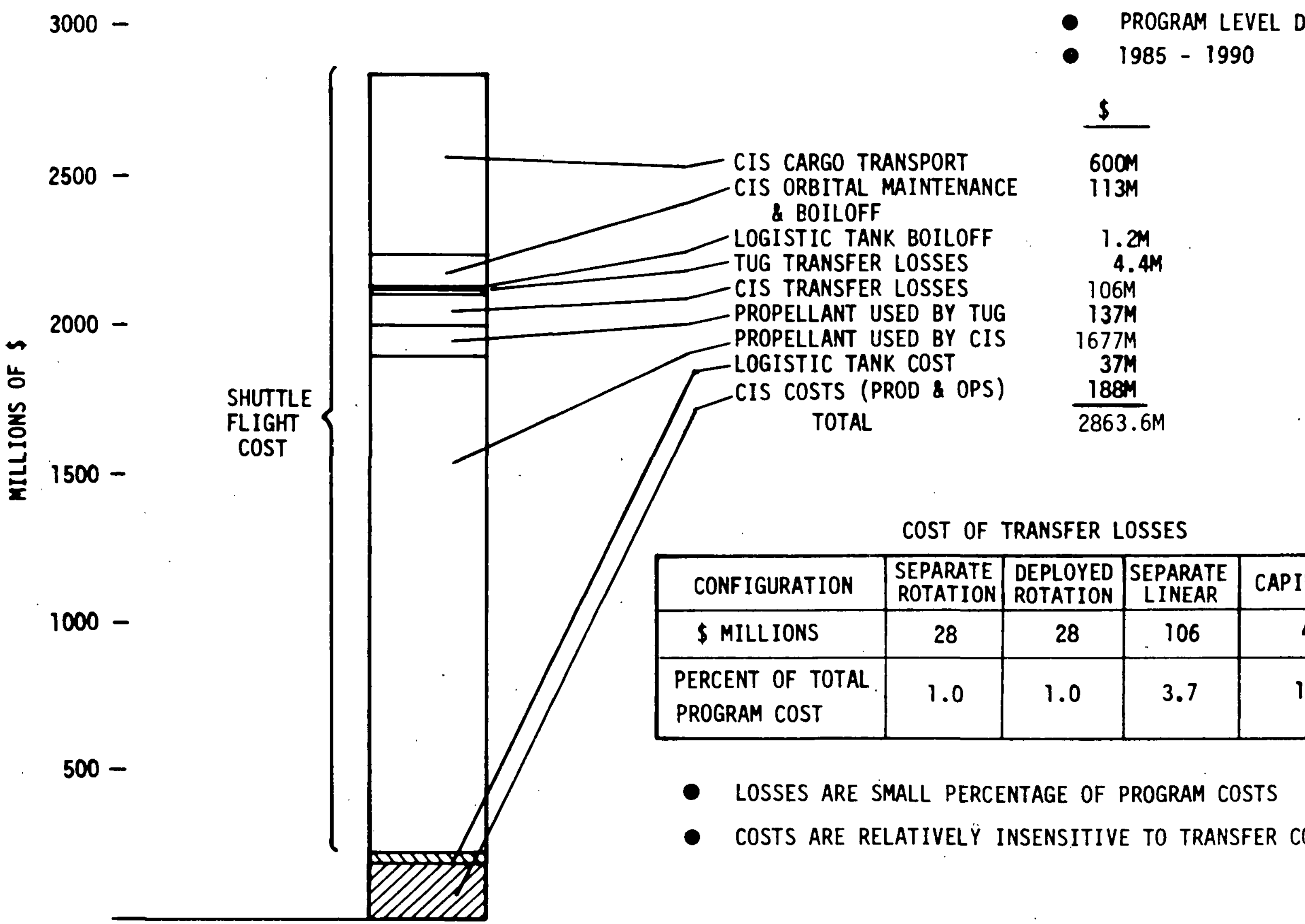
Table 6.1.1-4 Comparative Propellant Transfer Losses for Direct Transfer to CIS

- BASED ON 15 HR AVERAGE TRANSFER TIME (8 TO 20 HRS)
- LOSSES IN % OF 60 K LBS
- LOSSES FOR AVERAGE TRANSFER

CONFIGURATION	SEPARATE ROTATION	DEPLOYED ROTATION	SEPARATE LINEAR	CAPILLARY
ACCELERATION, G'S	4×10^{-4}	2×10^{-4}	$10^{-4}/10^{-5}$	$0/10^{-3}$
APS PROPELLANT	.2	.2	2.9	0.3
LIQUID RESIDUALS	.2	.2	1.7	1.2
NPSP CONTROL	1.0	1.0	1.0	1.0
OTHER*	0.1	0.1	0.1	0.1
TOTAL	1.5	1.5	5.7	2.6

*PUMPING POWER, LINE RESIDUALS, LINE CHILLDOWN, AND HEAT LEAK

- TRANSFER EFFICIENCY DRIVEN BY APS PROPELLANT AND RESIDUALS
- NPSP CONTROL PROPELLANT LOSSES HIGH DUE TO LARGE CIS TANK VOLUME
- ROTATION MOST EFFICIENT TRANSFER MODE



COST OF TRANSFER LOSSES

CONFIGURATION	SEPARATE ROTATION	DEPLOYED ROTATION	SEPARATE LINEAR	CAPILLARY
$ MILLIONS	28	28	106	49
PERCENT OF TOTAL PROGRAM COST	1.0	1.0	3.7	1.7

- LOSSES ARE SMALL PERCENTAGE OF PROGRAM COSTS
- COSTS ARE RELATIVELY INSENSITIVE TO TRANSFER CONCEPT

Figure 6.1.1-11 Logistic Program Costs, Direct Transfer to CIS

are indicated. Of particular interest is the cost of the propellant transfer losses as a function of the propellant transfer configuration. A comparison of the cost of transfer losses and the percentage of total program cost that the losses represent is made for various transfer configurations. As indicated, the costs of the transfer losses for all configurations are small when compared with the total program costs. As was concluded for transfer to tug, program costs for CIS are relatively insensitive to the propellant transfer configuration and factors other than costs are the drivers influencing configuration selection.

The orbital mechanics of a linear acceleration transfer technique were analyzed to establish preferred modes of operation. Thrust vector orientation was analyzed for two modes, in-plane and cross-plane (normal to shuttle orbital plane) using an NR flight mechanics control program. The line-of-sight separation distance between the thrusting tug/logistic module and the quiescent shuttle as a function of time was described for ten orbits (one 15-hour loading cycle). Also, the altitude above the earth was computed for the tug/logistic module during its thrusting cycle. These results are presented in Figure 6.1.1-12 and show that the in-plane technique results in an orbital path divergent to the initial orbit and will terminate in deorbit and earth impact within a few orbits. The cross-plane technique results in a cyclic orbital path which, under ideal conditions, is coincident with the initial orbit at one point on each revolution.

For this operation the tug/logistic module will be oriented and maintained in an attitude with the longitudinal axis of the vehicles perpendicular to the initial orbital plane and then cross-plane linear thrusting will be initiated by actuating the thrusters on the logistic module. Thrusting will be continuous for the full duration of the propellant transfer phase of the mission and will be terminated at the first optimum orbital position following completion of the transfer operation. The cross-plane technique has been evaluated using an NR Precision Trajectory Computer program. With a classic or ideal model, the locus of the thrusting body will return and be coincident with the reference or initial orbit at one point on each orbit (no delta V, delta inclination, or delta distance). However, when earth oblateness orbital perturbations are introduced, a separation of approximately 7 nautical miles will exist at the termination of the thrusting. This separation must be accounted for during the subsequent rendezvous with the orbiter. From these results, it was concluded that the cross-plane technique is a viable method for applying thrust to provide the acceleration force for propellant transfer.

6.1.2 Receiver Tank Thermodynamic Control

The concepts for providing the required thermodynamic control are shown on Figure 6.1.2-1 and involve either connecting the ullage of the supplier and receiver vehicle tanks or providing overboard venting of the receiver tanks. The connected ullage concept results in minimum propellant losses but requires positive liquid/vapor interface control in the receiver and additional line interfaces. The number of interface line connections is reduced by the overboard vent concept but the inherent propellant losses from venting are significant. A technique which vents the receiver tank to space prior to transfer eliminates the need for liquid/vapor interface control in the receiver since

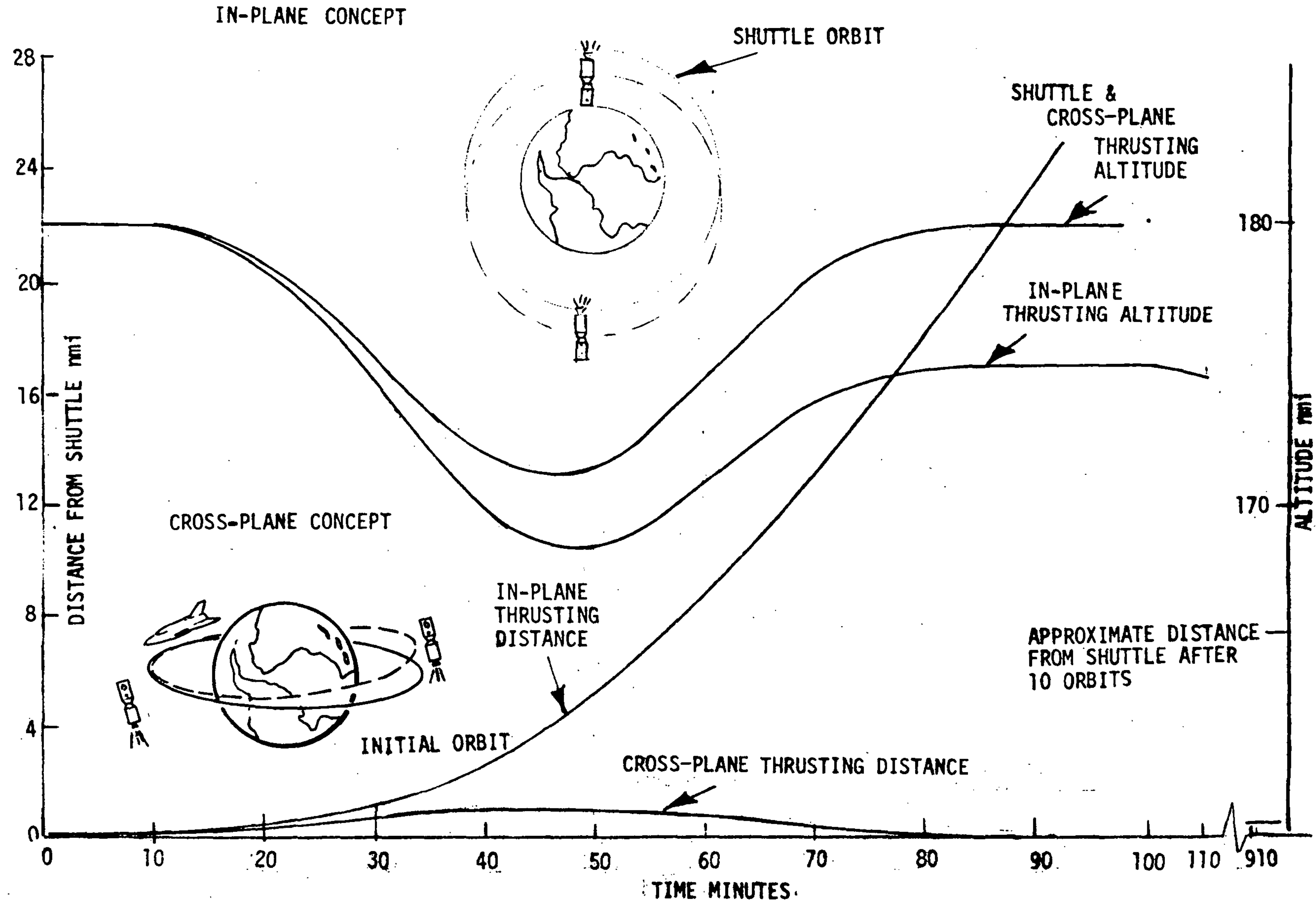


Figure 6.1.1-12 Linear Acceleration/Propellant Settling Orbital Mechanics

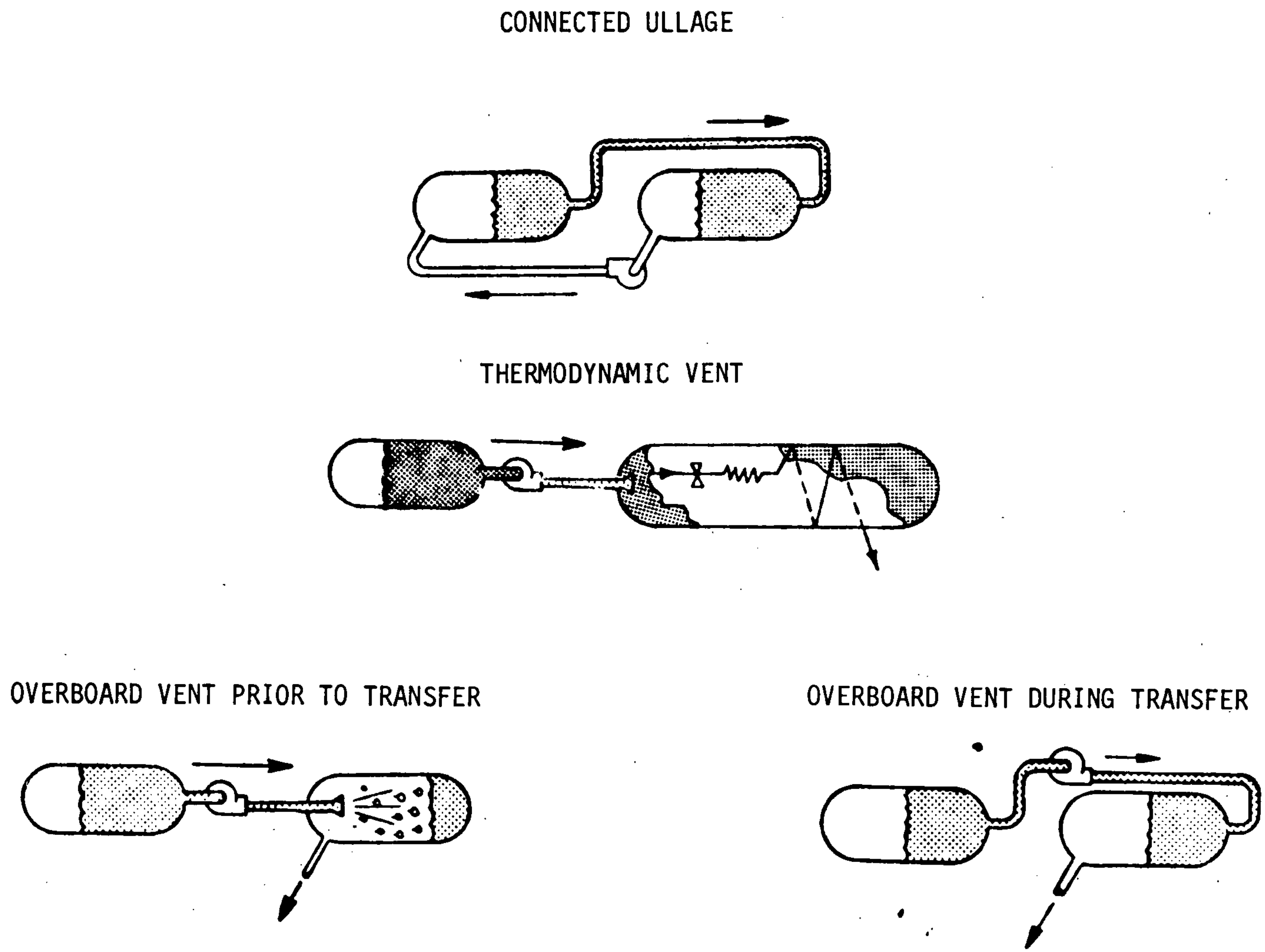


Figure 6.1.2-1 Candidate Receiver Tank Thermodynamic Control Concepts

the actual transfer is to the voided receiver tank with no venting required. This concept would involve the total loss of the pre-transfer residual propellants in the receiver and would also require a high degree of mixing within the receiver. Use of the receiver vehicle's existing thermodynamic vent system also precludes the necessity for positive liquid/vapor interface control in the receiver tank since this system allows the efficient venting of either liquid or gas.

Figure 6.1.2-2 shows the characteristics of the prior-to-transfer vent concept. Perfect mixing to achieve the heat transfer required to provide a homogeneous fluid temperature in the receiver was assumed and therefore represents idealized conditions. In practice, one might expect the full-tank ullage pressure to be higher than shown which might require thermodynamic venting and the associated propellant losses to restore the propellant to the desired thermodynamic balance.

Figure 6.1.2-3 shows the characteristics of the vent-during transfer concept. The losses shown for the RNS and tug vehicles represent the gas which must be vented from the receiver to allow stabilized conditions at the conclusion of the transfer. Complete liquid/vapor separation with no two-phase venting is assumed.

Use of the receiver vehicle's existing thermodynamic control was analyzed during the OPSS study for the case of a complete user vehicle filling during a single transfer from a depot. For this case, the flow capacity of the user vehicle thermodynamic vent system was too low to allow propellant transfer in a reasonable length of time. For the case of propellant transfer directly from a logistic module to the CIS, 19 transfers are required over a period of 80 days. This longer fill time will allow propellant temperature and pressure control at a reduced vent flow rate. For this reason, a re-assessment has been made of the possibility of using the user vehicle's existing thermodynamic vent system for transfer operations.

The pressure traces shown on Figure 6.1.2-4 were based on propellant mixing, with the energy of compression and condensation of the displaced ullage going into the bulk of the liquid and raising the vapor pressure. The cooling rates were those required to condense exactly the displaced ullage over a period of 96 hours. When the tanks are nearly empty, mixing is not essential because the overall pressure rise due to compression is not great; but when the tanks are nearly full, periodic mixing is necessary to condense the displaced ullage or the overall pressure rise becomes prohibitively large.

The results of this analysis show that the use of the existing user vehicle thermodynamic vent system during the transfer operation is feasible for the case where a complete fill requires several partial transfers over an extended period of time. Use of this concept improves the feasibility of those rotational and capillary liquid/vapor interface control concepts which do not provide positive or predictable propellant orientation in the receiver tank. However, use of this concept would introduce some user vehicle impact due to the additional requirement for bulk liquid mixers, increased thermodynamic vent system flow capability, and increased vent system control complexity.

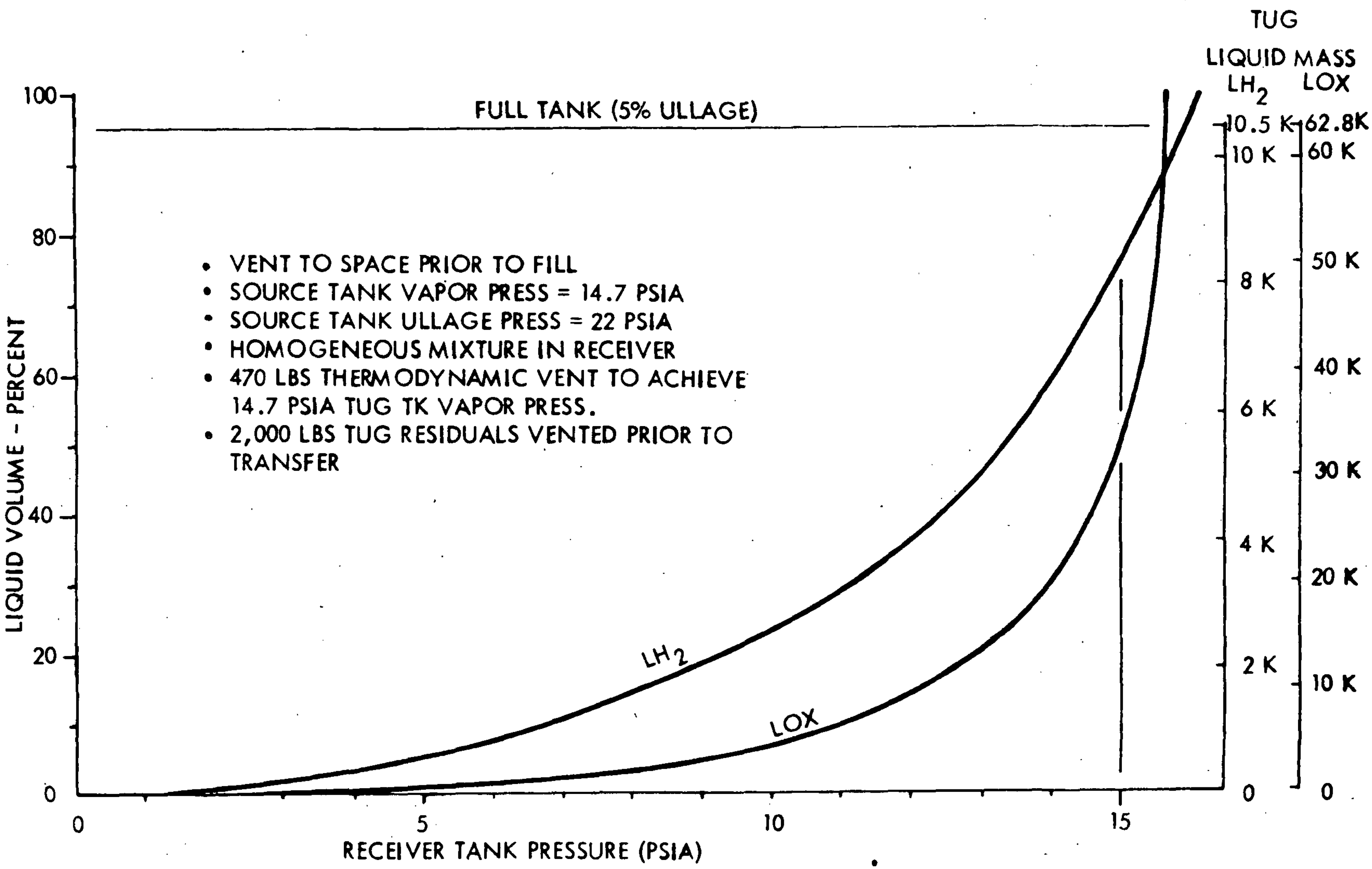


Figure 6.1.2-2 Overboard Vent Prior to Transfer

PROPELLANT LOST BY OVERBOARD VENT DURING FILL

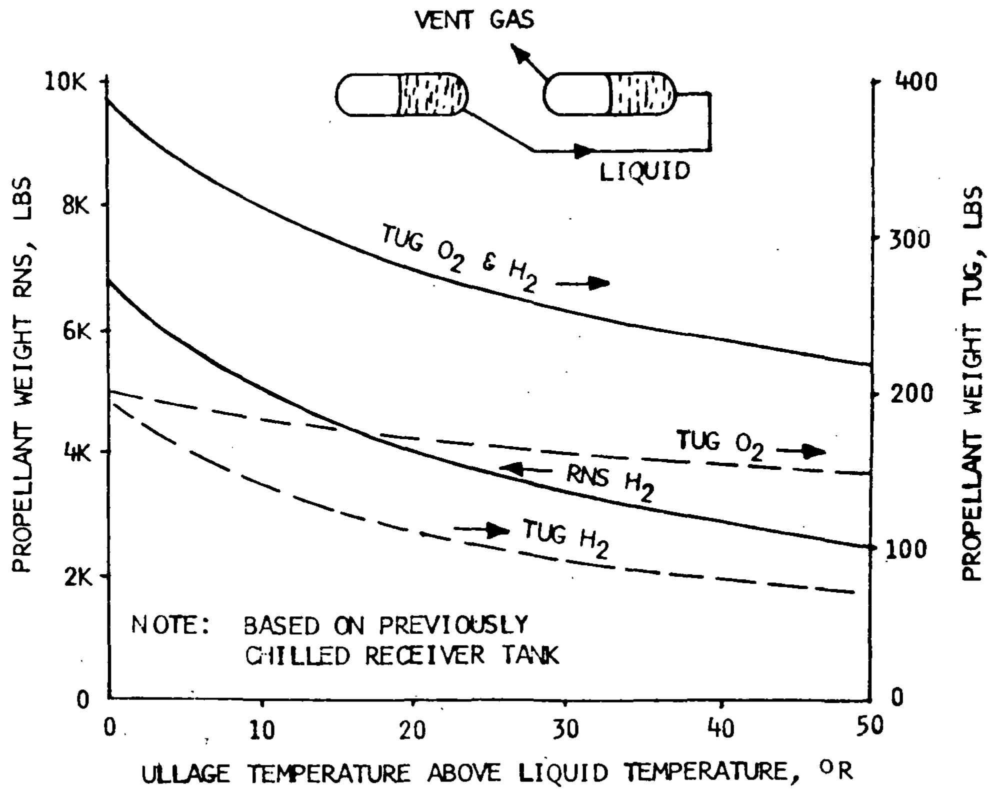
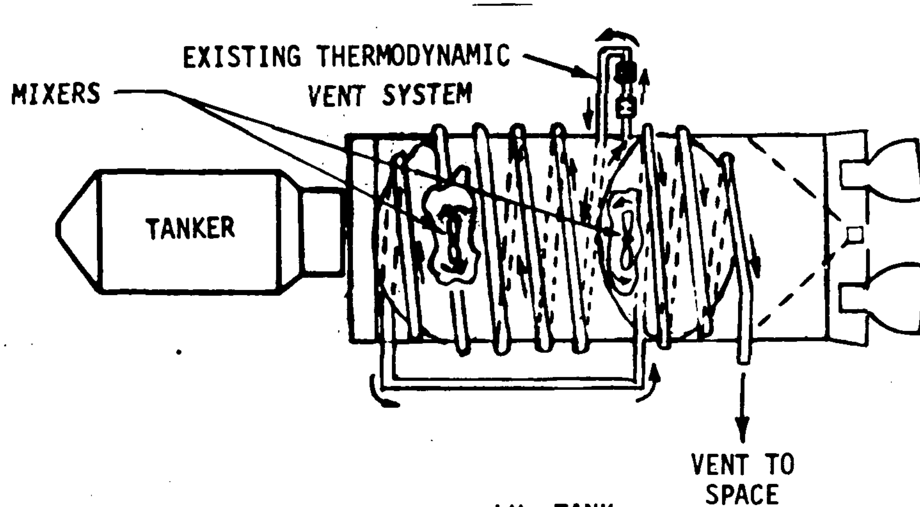
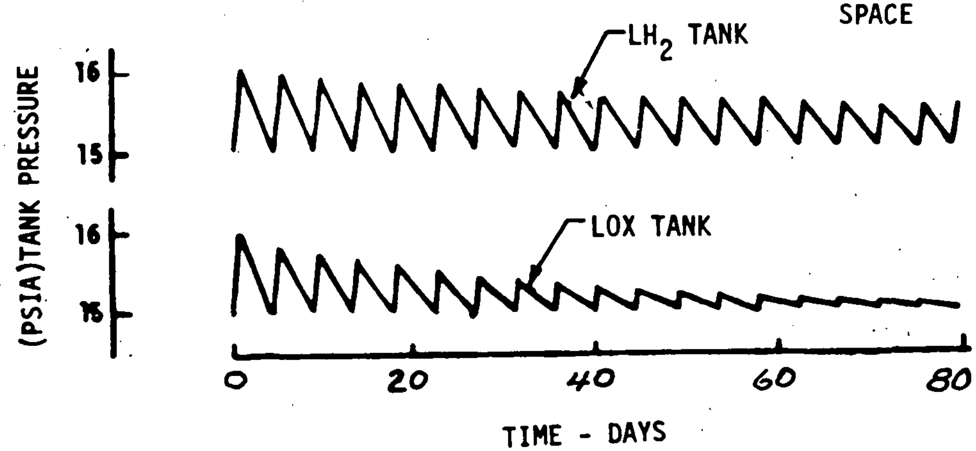


Figure 6.1.2-3 Overboard Vent During Transfer





- EXISTING USER VEHICLE THERMODYNAMIC VENT SYSTEM USED
- EFFICIENT VENTING OF LIQUID OR GAS
- FEASIBLE DUE TO LONG PERIODS BETWEEN TRANSFERS
- MIXERS REQUIRED TO AVOID EXCESSIVE TANK PRESSURE
- NO VENTING OF OXYGEN

Figure 6.1.2-4 Thermodynamic Venting During Transfer

The characteristics of the thermodynamic control concepts discussed are summarized below. The connected ullage concept was selected as the baseline with the primary factor being low propellant losses.

Technique	Advantages	Disadvantages
Connected Ullage	°Min. Propellant Vent Loss °Provides Source Tank Liquid Displacement °Liquid/Vapor Interface Control not Critical	°Liquid/Vapor Interface Control Required for Receiver °Additional Line Interfaces
Overboard Vent Prior to Transfer	°No Receiver Tank Liquid/ Vapor Interface Control Required	°Loss of User Vehicle Initial Propellant Residuals °Good Fluid Mixing Req'd
Overboard Vent During Transfer	°No Gas Return Line Required	°Source Tank Gas Supply Required for Liquid Displacement °Liquid/Vapor Interface Control Critical
Thermodynamic Vent During Transfer	°No Receiver Tank Liquid/ Vapor Interface Control Required	°Bulk Liquid Mixers Req'd °Increased Vent System Flows Required °Increased Vent System Control Complexity

6.1.3 Expulsion

The most promising concepts for liquid expulsion involve one of the following: (1) displacement of the fluid by pumping; (2) displacement of the fluid by pressurization, or (3) positive displacement of the fluid by mechanical devices in the supplier tanks. Several variations of these concepts are depicted on Figure 6.1.3-1.

Figure 6.1.3-2 shows the parametric hydrodynamic characteristics for a 15-hour LH_2 logistic tank to tug pump transfer system concept. The significant penalty factors, pumping power, line residual, line weight, and line boiloff, are presented as a function of transfer line diameter. As shown by the figure,

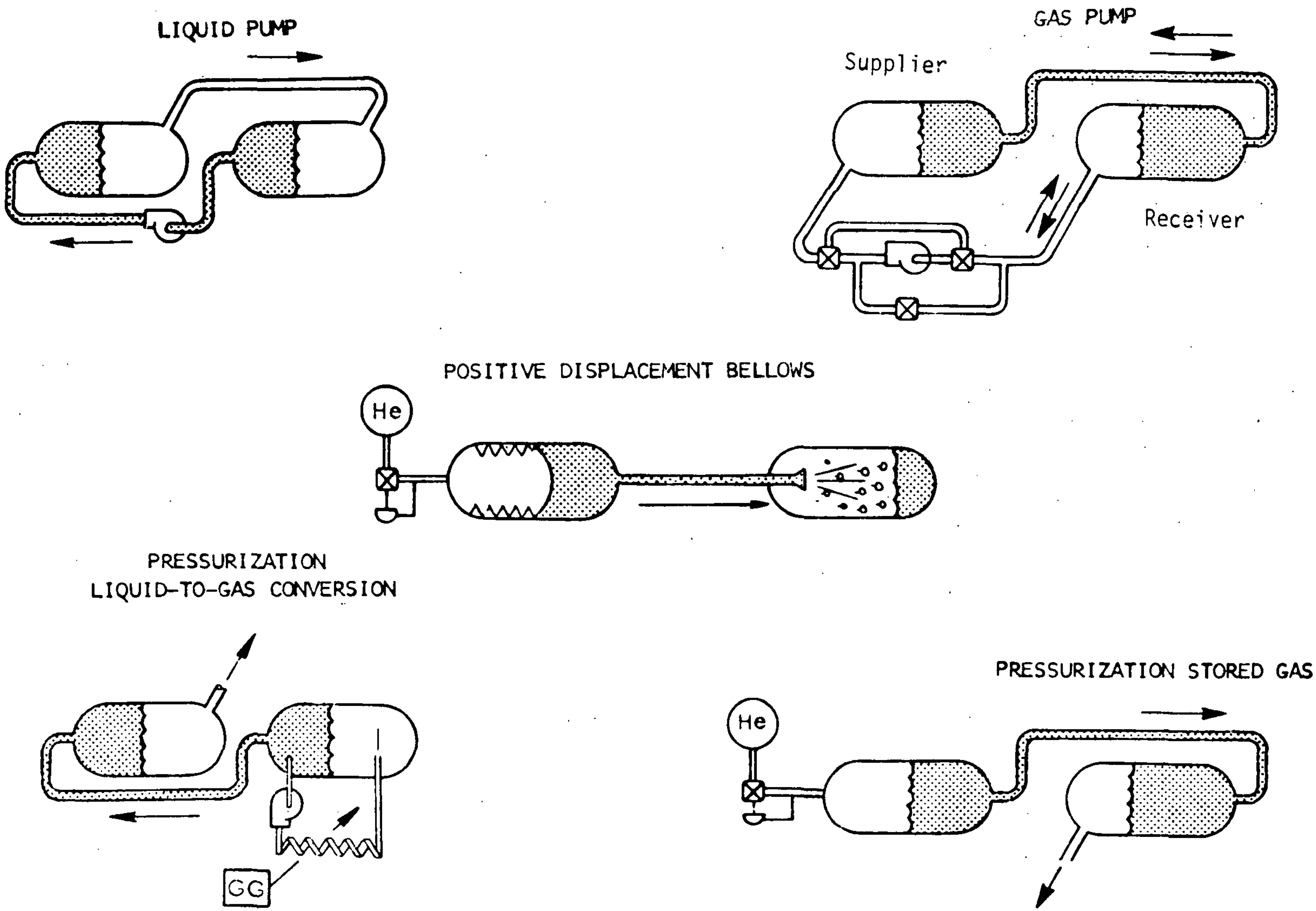


Figure 6.1.3-1 Candidate Liquid Expulsion Concepts

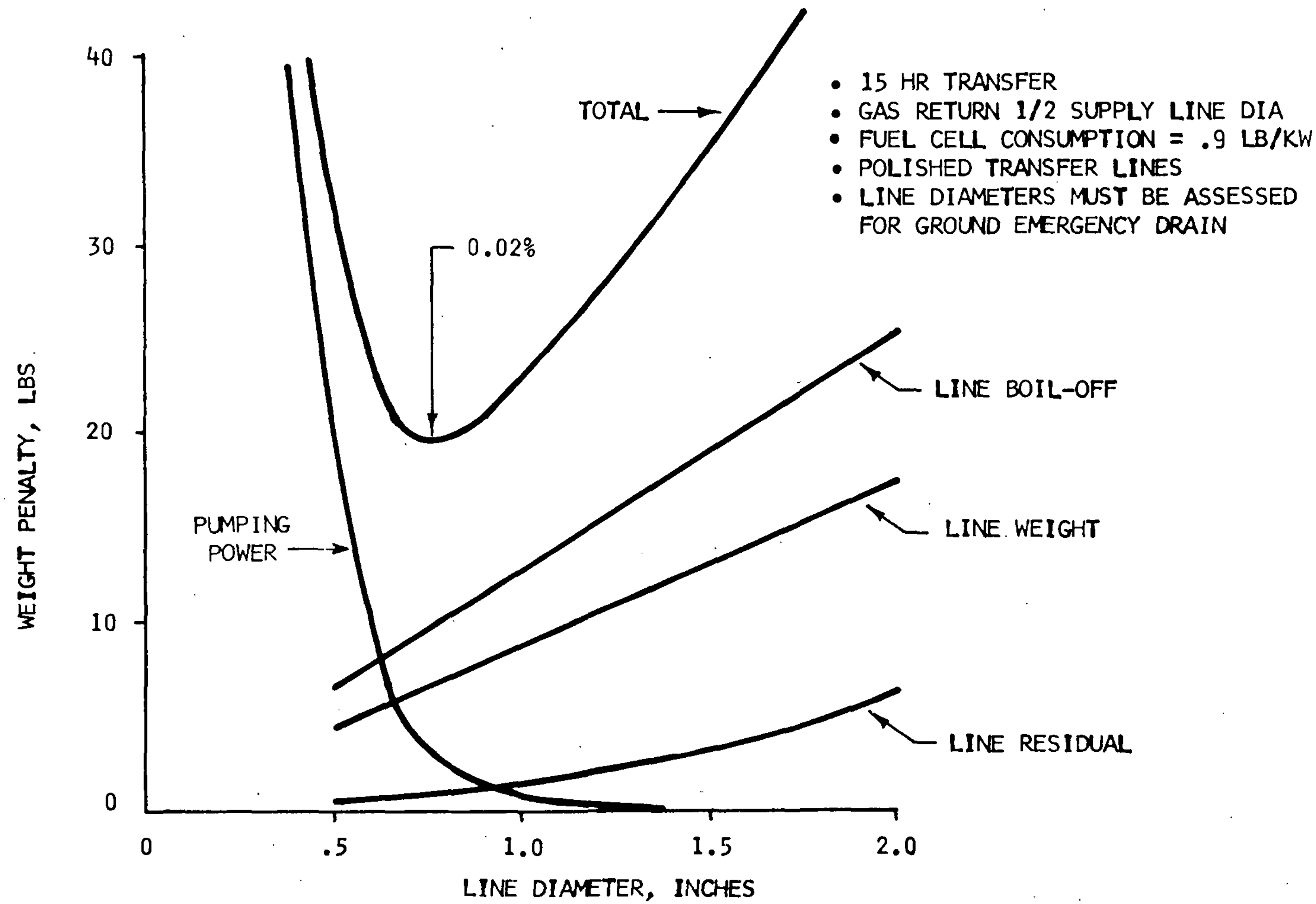


Figure 6.1.3-2 Logistic Tank-to-Tug LH_2 Transfer Line Diameter

the penalty is only 0.02 percent for a line size of approximately 0.8 inch diameter. Attention is called to the pumping power curve which indicates that the pumping power loss is insignificant.

The power requirement for propellant transfer is a function primarily of propellant density, propellant flow rate and transfer line size. The following equation was used for obtaining power.

$$Hp = \frac{0.95\ f\ L\ \dot{W}^3}{w^2\ D^5\ \eta}$$

HP = Horse Power

f = .02 line friction factor

L = Line equivalent length (inch)

$\dot{W}$ = Liquid propellant flow rate (lb/sec)

w = Liquid propellant density (lb/ft^3)

D = Line diameter (inch)

η = 50 percent pump and motor combined efficiency

Transfer pump horsepower values, computed as a function of line diameter for the different vehicles, are plotted on Figures 6.1.3-3 and 6.1.3-4 for LH_2 and LO_2 transfers, respectively. The baseline diameters were selected as indicated to minimize impact on the appropriate user vehicle's power supply system.

Except as modified by slight changes in efficiency, the pumping power data developed is generally applicable to gas and liquid pumps. Whenever possible, a cryogenic liquid pump is normally submerged within the propellant tank to minimize NPSH requirements and avoid cavitation. A gas pump, however, is more readily adaptable to an in-line installation. For propellant transfer, this would facilitate the design of a manifolding and valving arrangement for immediate flow reversal, if required, in an emergency or for any other reason. Pump accessibility for maintenance or replacement is also greatly improved through the use of an in-line mounted gas pump.

Figure 6.1.3-5 shows a penalty comparison of vapor pressurization, helium pressurization, and pump expulsion for a 15-hour logistic module to tug oxygen transfer. These data indicate that the pump concept has the lowest penalty with oxygen pressurization the highest. Although not presented here, similar data for the LH_2 system show the pump with the lowest and the helium pressurization with the highest penalty.

Figure 6.1.3-6 presents some of the more salient features of a positive displacement bellows concept. The most attractive features of a positive displacement concept are: (1) liquid/vapor interface control is inherent, and (2) it has the potential of reducing the liquid residuals to a minimum.

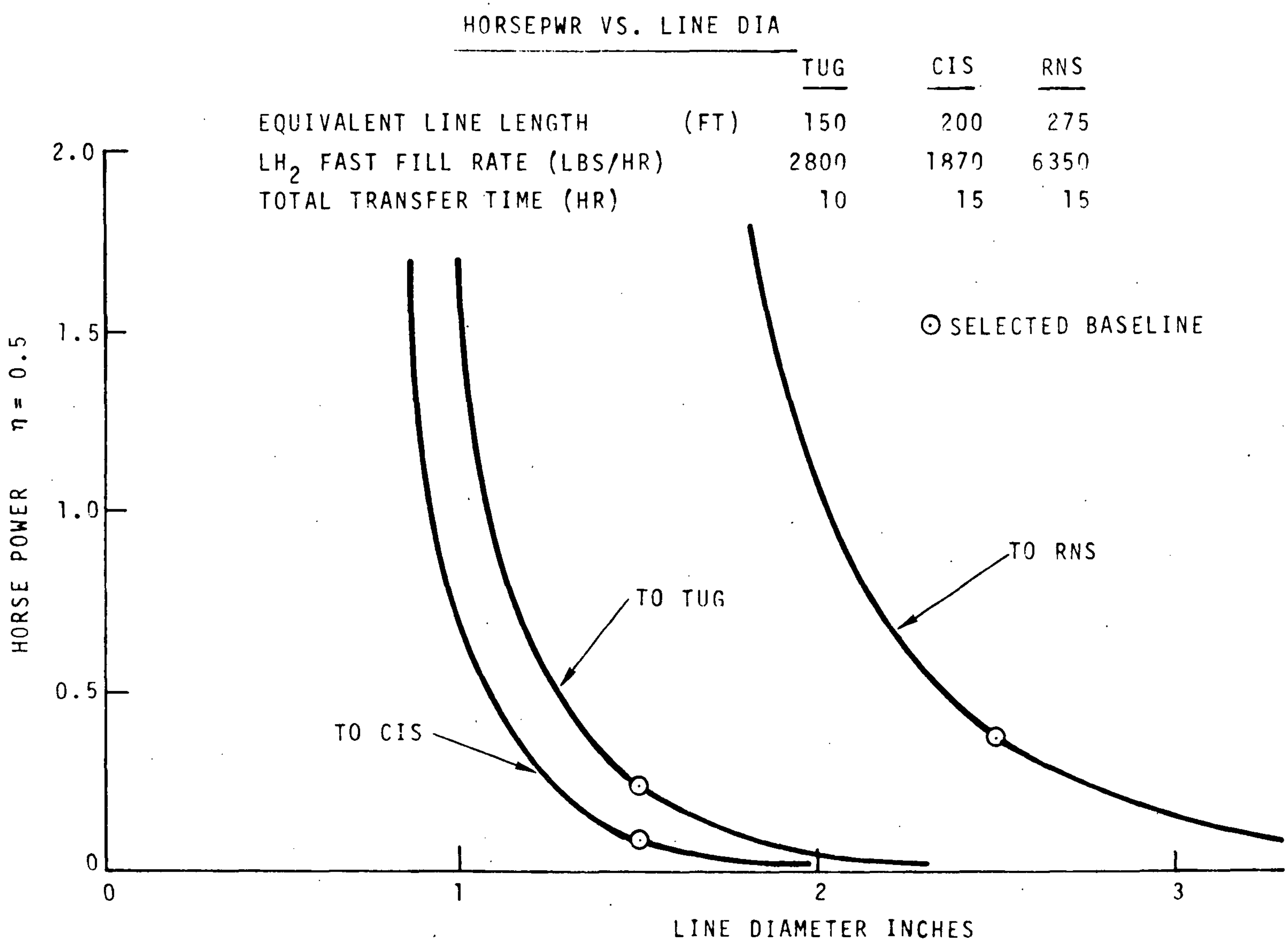


Figure 6.1.3-3 LH_2 Transfer from Logistics Tank Power

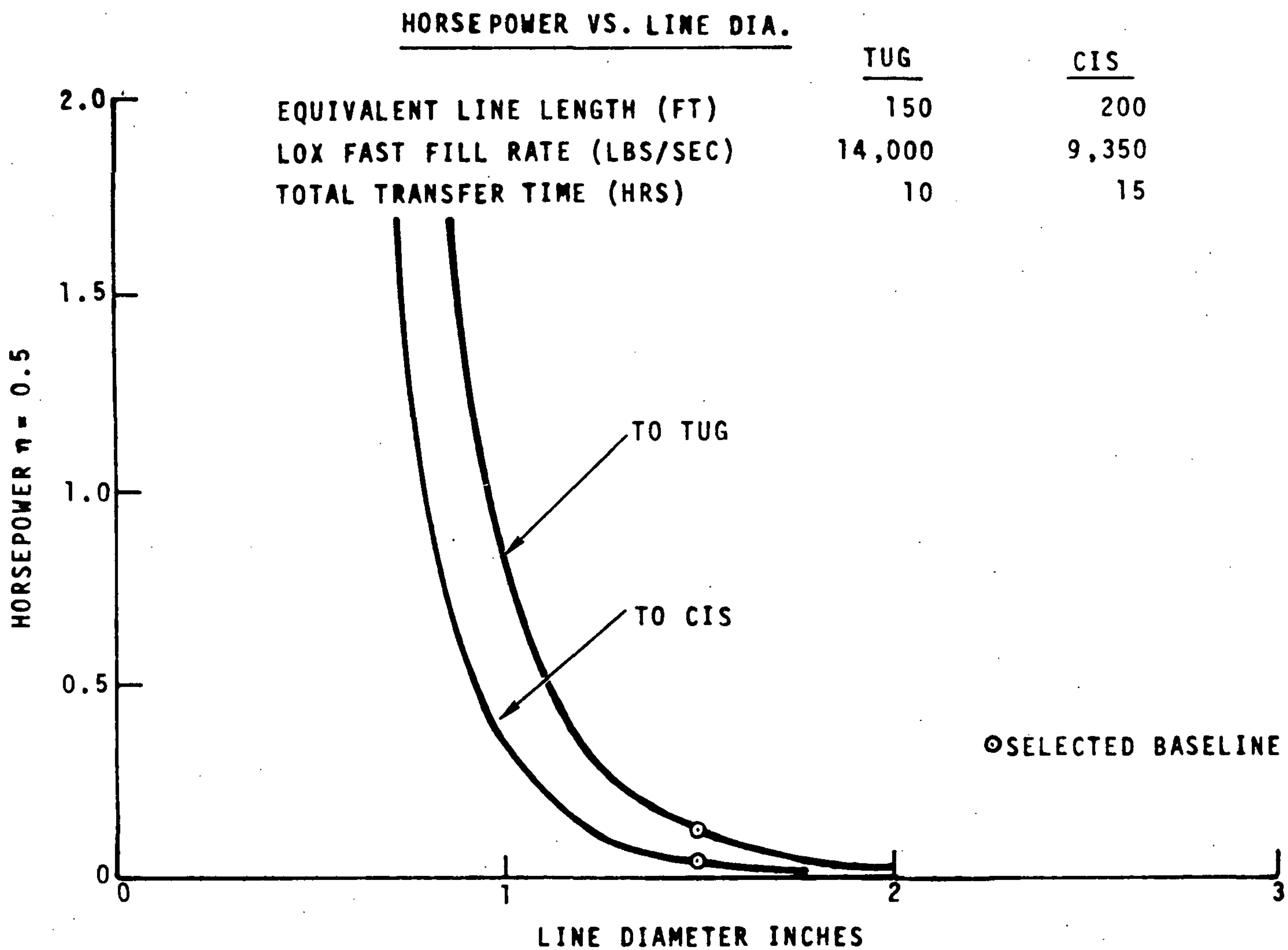


Figure 6.1.3-4 LOX Transfer from Logistics Tank Power

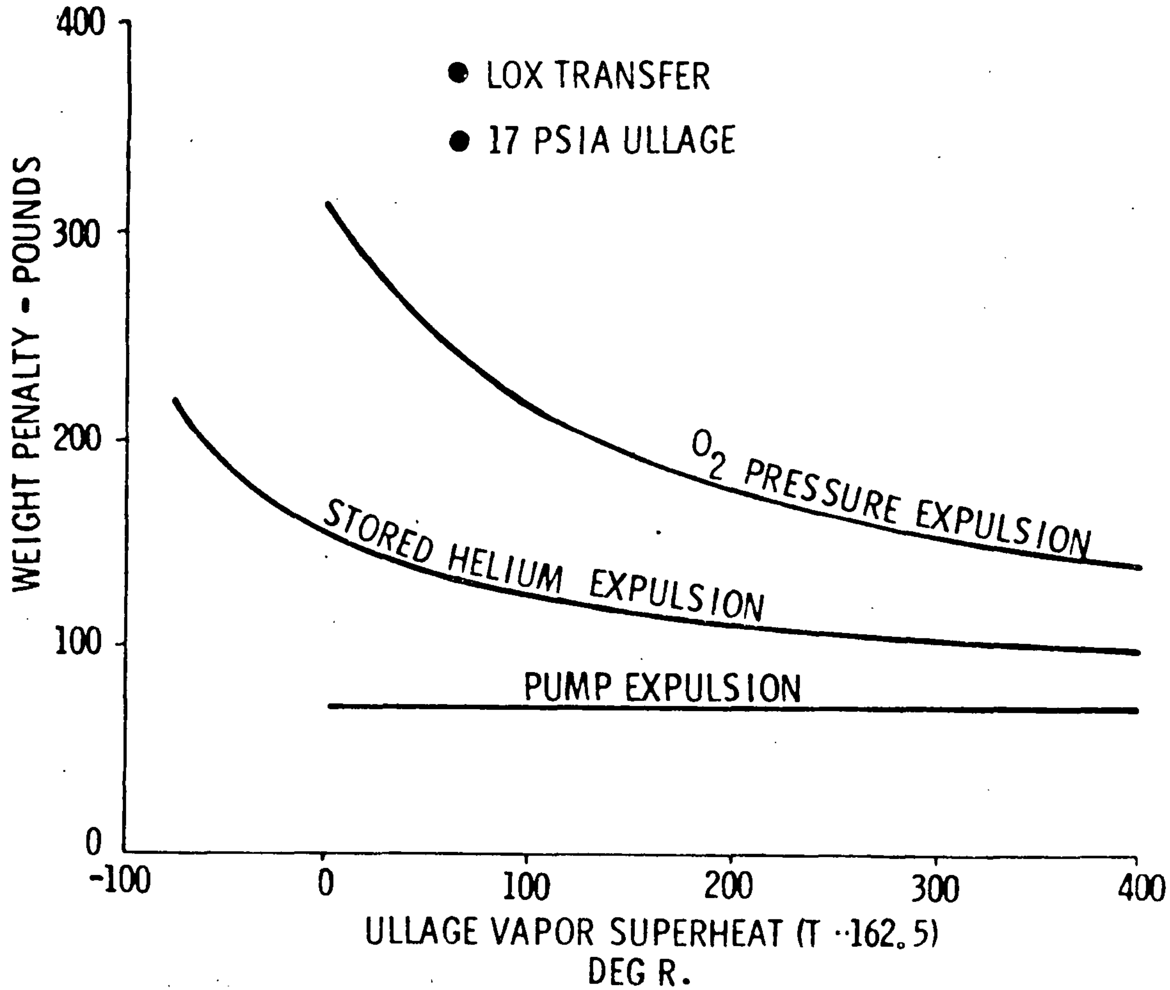
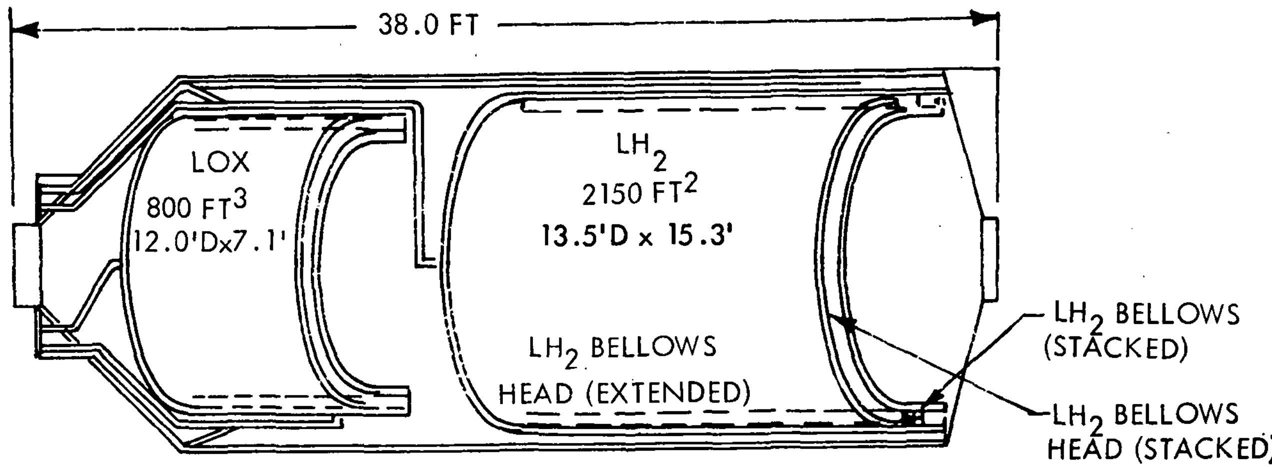


Figure 6.1.3-5 Comparison of Expulsion Concepts for Logistics Tank-to-Tug Transfer



ADVANTAGES	DISADVANTAGES
1. NO PROPELLANT SETTLING REQUIRED	1. PROPER VENTING OF BELLOWS DIFFICULT
2. SHUTTLE CAN REMAIN ATTACHED DURING TRANSFER OPERATIONS	2. ΔP CRITICAL TO PREVENT BUCKLING
3. RESIDUALS MAY BE LOWER THAN FOR OTHER CONCEPTS	3. SUPPORT OF EXPANDED BELLOWS FOR ACCELERATION LOADING DIFFICULT
4. NO TRANSFER PUMPS REQUIRED	4. REQUIRES ACTUATION SYSTEM
5. NO GAS RETURN LINE REQUIRED	5. PURGING OR INERTING OF CONVOLUTIONS DIFFICULT
6. SMALL VOLUME TO INERT OR PURGE	6. TWO PHASE FLOW WHEN USED WITH VENT PRIOR TO FILL
	7. INCOMPATIBLE WITH "TOPPING-OFF"
	8. INCOMPATIBLE WITH MOST STATE-OF-THE-ART LIQUID GAUGING SYSTEMS
	9. FLOW DIRECTION NOT REVERSIBLE

Figure 6.1.3-6 Bellows Concept for Positive Displacement Expulsion

However, there are a number of fabrication and operational characteristics which prevent the selection of this concept at this time. Some of the principal disadvantages are: large sizes are difficult to manufacture (equipment and technique are not available for sizes over 40 inches in diameter), hardware weight is high, and, as listed on Figure 6.1.3-6, an unusually high number of compatibility and operational problems are anticipated.

The characteristics of the concepts discussed are summarized below. The concept with a pump mounted in the vapor return system was selected as baseline. The performance of the gas pump concept and the liquid pump concept are essentially the same, however, the configurational design flexibility and the serviceability of the gas pump concept appear superior.

Technique	Advantages	Disadvantages
Liquid Pump	°Low Weight Penalty	°In-Tank Pump °Receiver Pump Required for Transfer Reversal °Maintenance - Poor Accessibility
Gas Pump	°Safety - Transfer Reversible °Low Weight Penalty °Maintenance - External Pump	°Higher Speed °Shorter Life
Positive Displacement	°No Propellant Settling Required	°Incompatible with User Configuration
Liquid/Gas Conversion Pressurization	°Lighter than Stored Gas for LOX	°Weight Penalty for Gas Generation °Incompatible with Connected Ullage
Stored Gas Pressurization	°Tank Purging Initiated if Required °Lighter than Liquid/Gas Conversion for LH_2	°Weight Penalty for Gas Supply °Incompatible with Connected Ullage

6.1.4 Net Positive Suction Pressure Control

Propellant transfer accomplished by pumping fluid between the tanks will require control of the NPSP (net positive suction pressure). The ullage pressure

must be maintained above the vapor pressure with sufficient margin to prevent boiling and two-phase flow in the transfer lines and receiver tank inlet. Alternately, the complete system could be designed for mixed phase flow. Figure 6.1.4-1 illustrates these two concepts. Mixed phase conditions in the transfer lines and tanks could be expected with the self-pressurization concept. An active pressurization system can be designed to provide the margin required to insure liquid phase transfer.

Figure 6.1.4-2 data generated during Study 8, Cryogenic Acquisition and Transfer, which was conducted by NR as part of the Saturn S-II Advanced Technology Studies (Reference SD71-768), show that bubble collapse times resulting from an increase in ullage pressure can be relatively long even though the fluid is instantly subcooled by the pressure level change. These data assume that the bubbles are collapsed by convection heat transfer in the liquid and mass transfer between the liquid and the bubble. An analysis of this type will tend to produce conservative data or maximum collapse times with factors such as propellant agitation and the existence of a firm liquid/vapor interface reducing the collapse time. Although collapse times in an operating system would tend to be shorter than those shown, it is concluded that it is undesirable for the bulk propellant to become saturated during transfer operations, such as may be the case if a self-pressurization concept were to be employed.

Figure 6.1.4-3 shows the weight penalty including system hardware for stored helium and liquid-to-gas conversion active NPSP control systems for both LH_2 and LOX. The weight of the propellant required to provide a 2 psi NPSP for the logistic module and tug, and similar data for the CIS, are shown on Figure 6.1.4-4.

The characteristics of the NPSP control concepts discussed are tabulated below. It was concluded that the development risk for a self-pressurization system was unacceptable at this time. Therefore, active pressurization was selected as baseline.

Technique	Advantages	Disadvantages
Self-Pressurization	°Passive System °No Propellant Losses	°Boiling (Two-Phase) Flow °Gas Entrapment in User Capillary Devices °Poor Performance Predictability
Active Pressurization	°All Liquid Transfer Flow °Good Performance Predictability	°Significant Propellant Losses °Active System Required

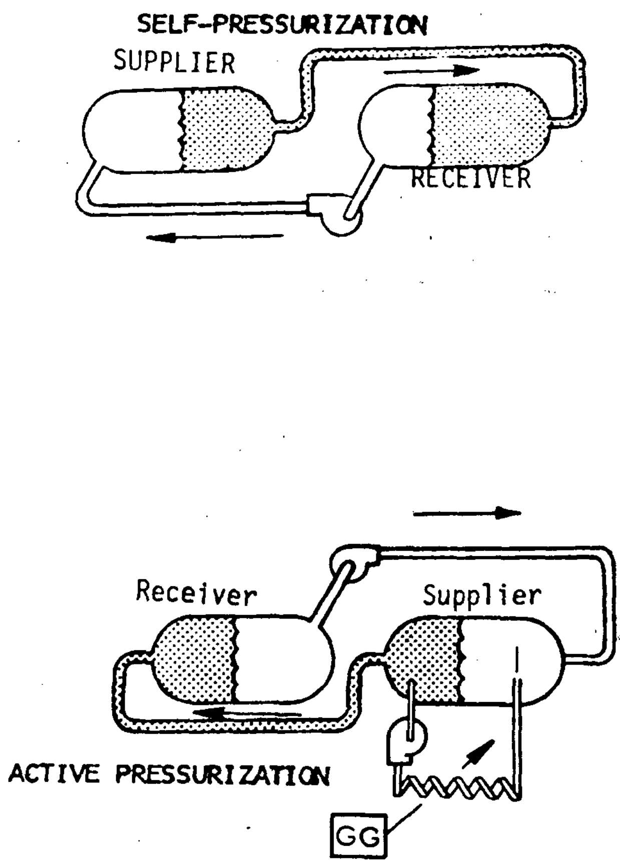


Figure 6.1.4-1 Candidate NPSP Control Concepts

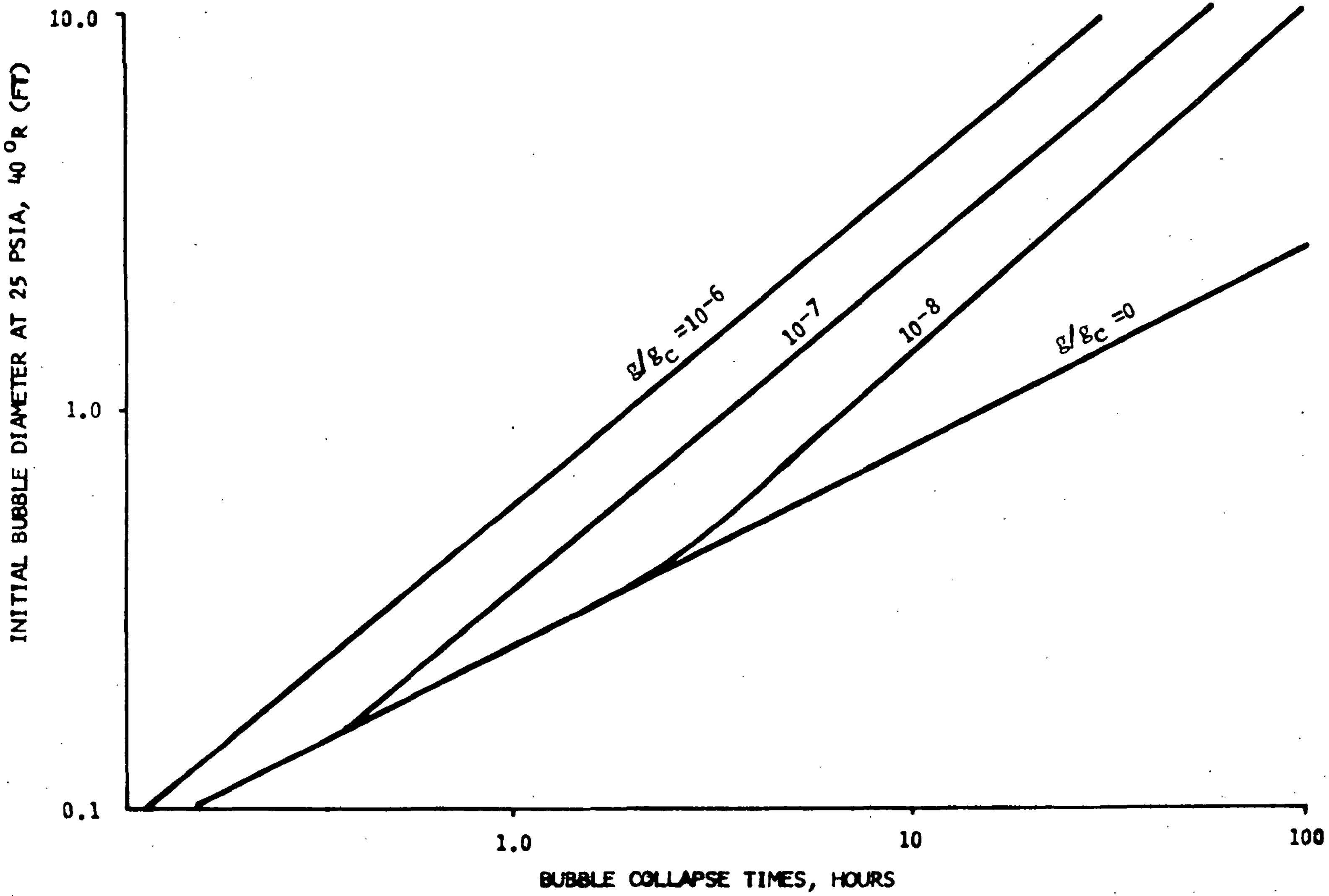


Figure 6.1.4-2 Bubble Collapse Times for Hydrogen Vapor in Liquid System Suddenly Pressurized from 15 to 25 PSIA

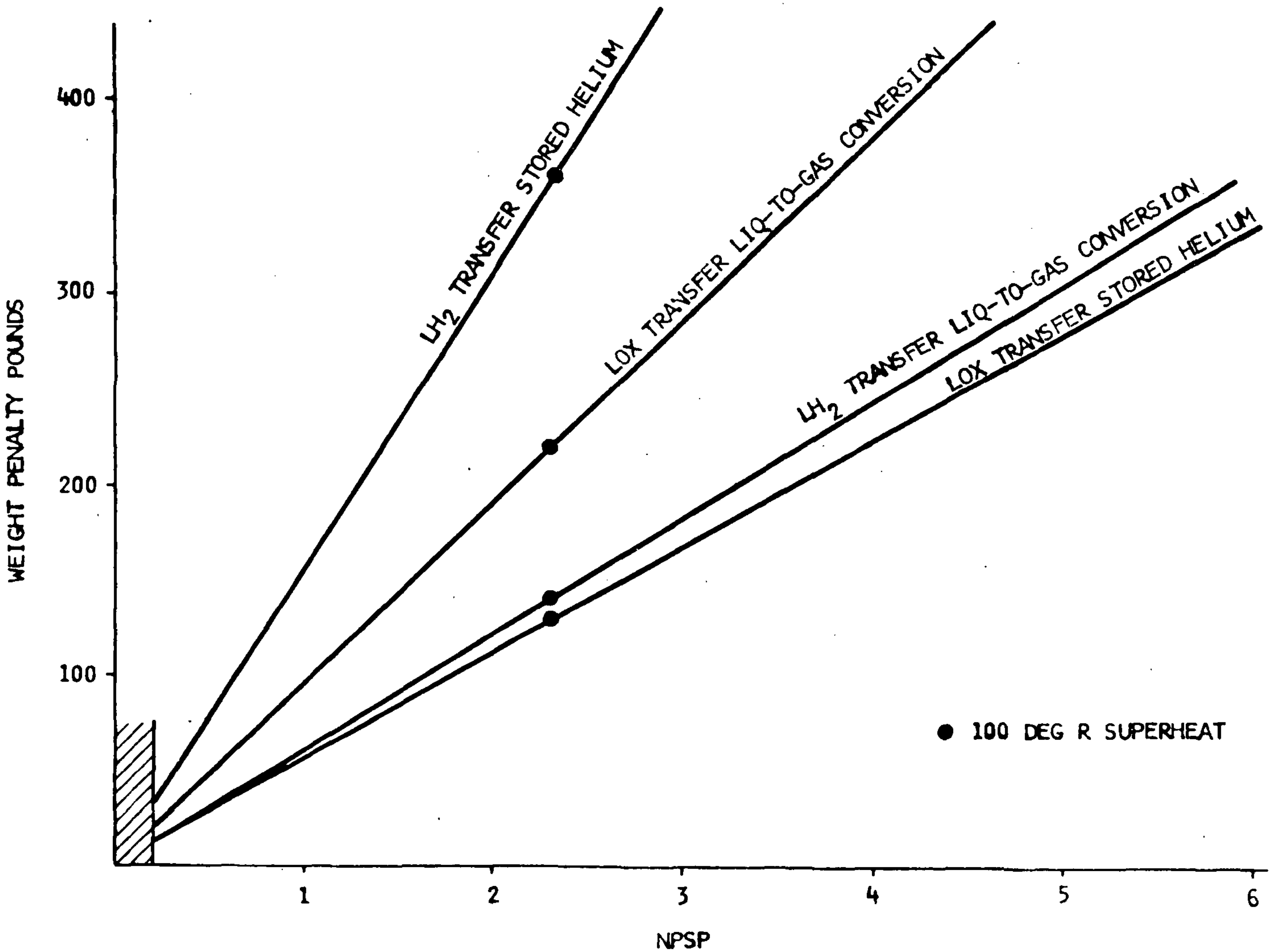


Figure 6.1.4-3 NPSP Control for Logistic Tank-to-Tug Transfer

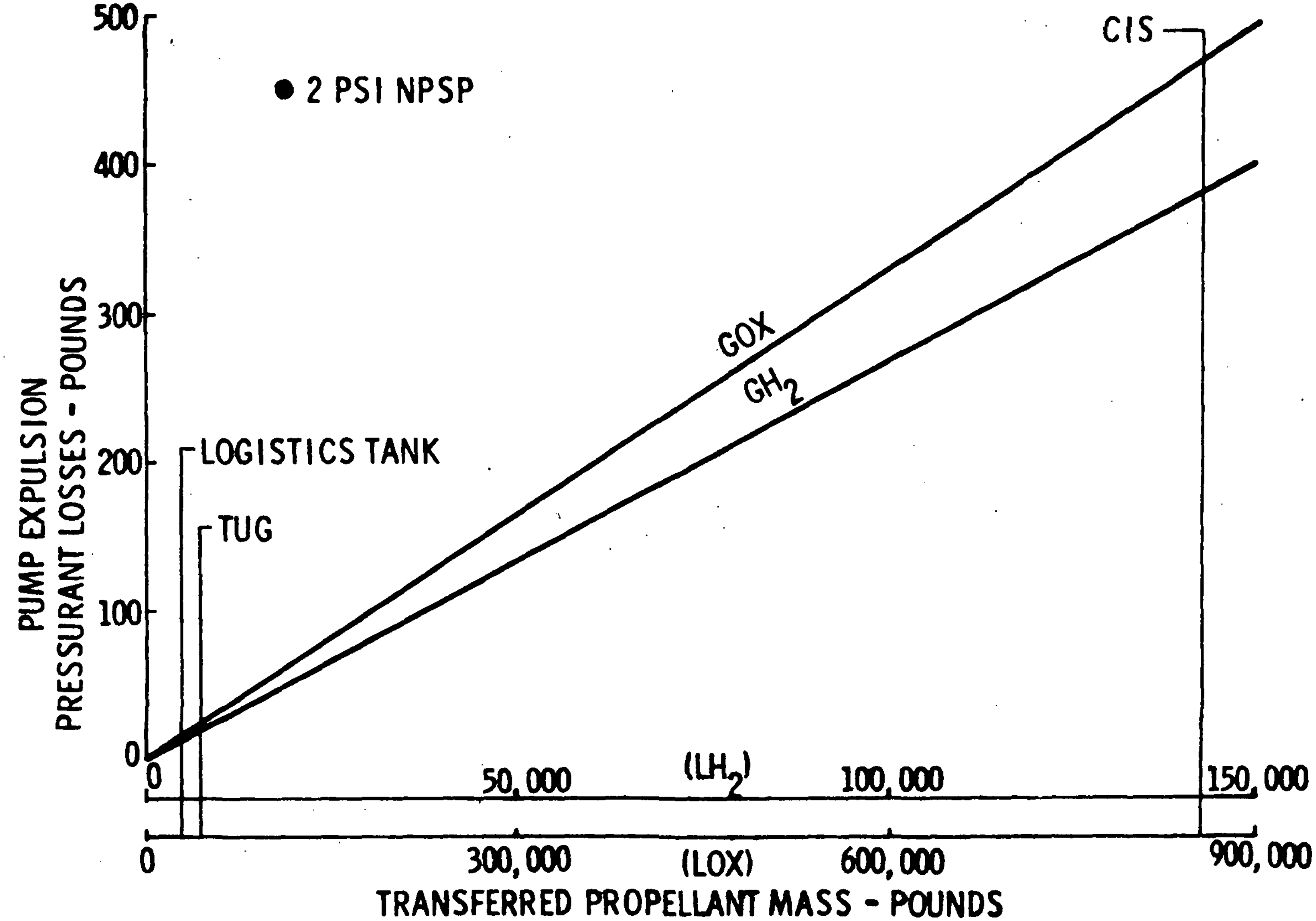


Figure 6.1.4-4 Pressurant Losses for NPSP Control

6.2 PROPELLANT GAUGING AND PROPULSION SUBSYSTEMS

Two important transfer subsystems have had a significant impact on the selection of a baseline orbital propellant transfer system. These are propellant gauging and the propulsion system providing propellant settling thrust. The influence of the requirements for these subsystems has been described in the previous section as each candidate transfer concept was discussed. Because of their important role in the conceptual definition of an orbital propellant transfer system, separate trade studies were conducted for each and are described in Sections 7.0 and 9.0 of Volume III. The results of these trade studies are summarized in the following two sections.

6.2.1 Propellant Quantity Gauging

Propellant quantity measuring techniques were investigated to determine the potential impact of gauging system constraints upon the propellant transfer techniques and system configurations evaluated during the ISPLS study. A second objective was to select a logistic module gauging system for use with the ISPLS baseline propellant transfer system configuration concept. The logistic module propellant quantity gauging will be required to measure propellant quantity and liquid levels (1) during prelaunch propellant loading operations, (2) during in-flight propellant jettison operations, (3) during orbital propellant transfer and flow control, and (4) for termination of orbital propellant transfer operations. The quantity measurements must be made under acceleration levels varying from the high levels during boost operation and the one-g level during ground loading to levels approaching zero during orbital operations. The system selected should fulfill both the high g and low g conditions with suitable accuracy and reliability.

Three zero g concepts were evaluated for their potential in satisfying these requirements. These were acoustic compliance, acoustic resonance, and nucleonic type systems. The accuracy and reliability of the present "state of the art" zero g type of gauging systems were found to be deficient for ISPLS operations. In addition, because of the selection of an acceleration mode of orbital propellant transfer, a zero g type of system is not required.

For positive acceleration environments, two "off-the-shelf" concepts and one new arrangement of an established technique were examined. These systems were respectively capacitance probes, discrete point sensors (horizontal resistance type sensing element), and a resistance wire concept utilizing a vertical wire resistance type sensor. The latter concept is a modification of the heated resistance wire technique which is presently utilized in the discrete point sensor system used in the S-II stage. To minimize the meniscus or capillary errors and to provide contiunuous quantity measurements the resistance wire is mounted on or parallel to the longitudinal axis of the tanks. The wires would be arranged in overlapping segments extending the full length of the tank with each segment on the order of three feet in length.

The low g characteristics of the coaxial tube capacitance probe were found to be completely unacceptable for the ISPLS propellant transfer system due to the capillary wetting or filling of the space between the inner and outer tube of the probe. The discrete point sensor is also unacceptable for low g application; the meniscus error for LH_2 at 10^{-5} g is on the order of 20 inches.

Although capillary errors will still be present with the small diameter (.005 to .010 inch) vertical resistance wire configuration, it is anticipated that the meniscus error will be on the order of three inches in contrast to the 20-inch error of the horizontally mounted sensor. In addition to the superior low g characteristics anticipated for the vertical resistance wire technique, it is well adapted to continuous measurement of the quantity over the complete capacity of the tank and can be self calibrated by a technique using two current levels.

For the reasons stated above, the selected baseline propellant quantity gauging technique for the ISPLS logistic module is the vertically mounted resistance wire concept. The configuration of this concept is depicted in Figure 6.2.1-1. Although at this time such a system would require development effort, it is concluded that it is potentially far superior to the other concepts evaluated. Since research and development effort is presently being expended on the zero g concepts mentioned above and new concepts can be expected in the future, this selection is for use in the ISPLS study at this time, and gauging techniques must be re-evaluated at the time of future application. A detailed description of the propellant gauging trade evaluation conducted is contained in Section 9.0 of Volume III.

6.2.2 Propulsion System for Propellant Transfer

An important aspect of the ISPLS study was an evaluation of radial versus linear thrusting as a means of accelerating the logistics module together with its user vehicle to provide the required liquid/vapor interface control. The thrusting requirements of these two techniques are different. For the radial technique, thrusting is used to provide the angular acceleration to spin up the module and its user to the rotational speed required to produce propellant settling by radial acceleration or centrifugal force. Once at the required rotational speed the unit will tend to rotate freely with no further acceleration thrust required and will continue to rotate in this manner for the full duration of the transfer. At the conclusion of the transfer the rotating body must be decelerated by counter thrusting.

For linear acceleration, thrusting is constant and at a level to produce the required propellant liquid/vapor interface control or settling force. The life cycle requirements of the techniques are different with the linear concept requiring longer thrusting applications and therefore requiring longer life cycles or more frequent replacement of the components.

Since the linear technique has been selected as the baseline concept for the final phase of the ISPLS study, the thrusting requirements for the linear technique were used for this evaluation. As a result of this analysis, the cryogenic bipropellant concept using LOX/LH_2 propellants was selected as the baseline propellant transfer propulsion system for the ISPLS study. This selection was based primarily upon the high performance achievable and upon the system simplicity and commonality which is a result of using the same propellants as used for the primary systems of the logistics module and the user vehicle.

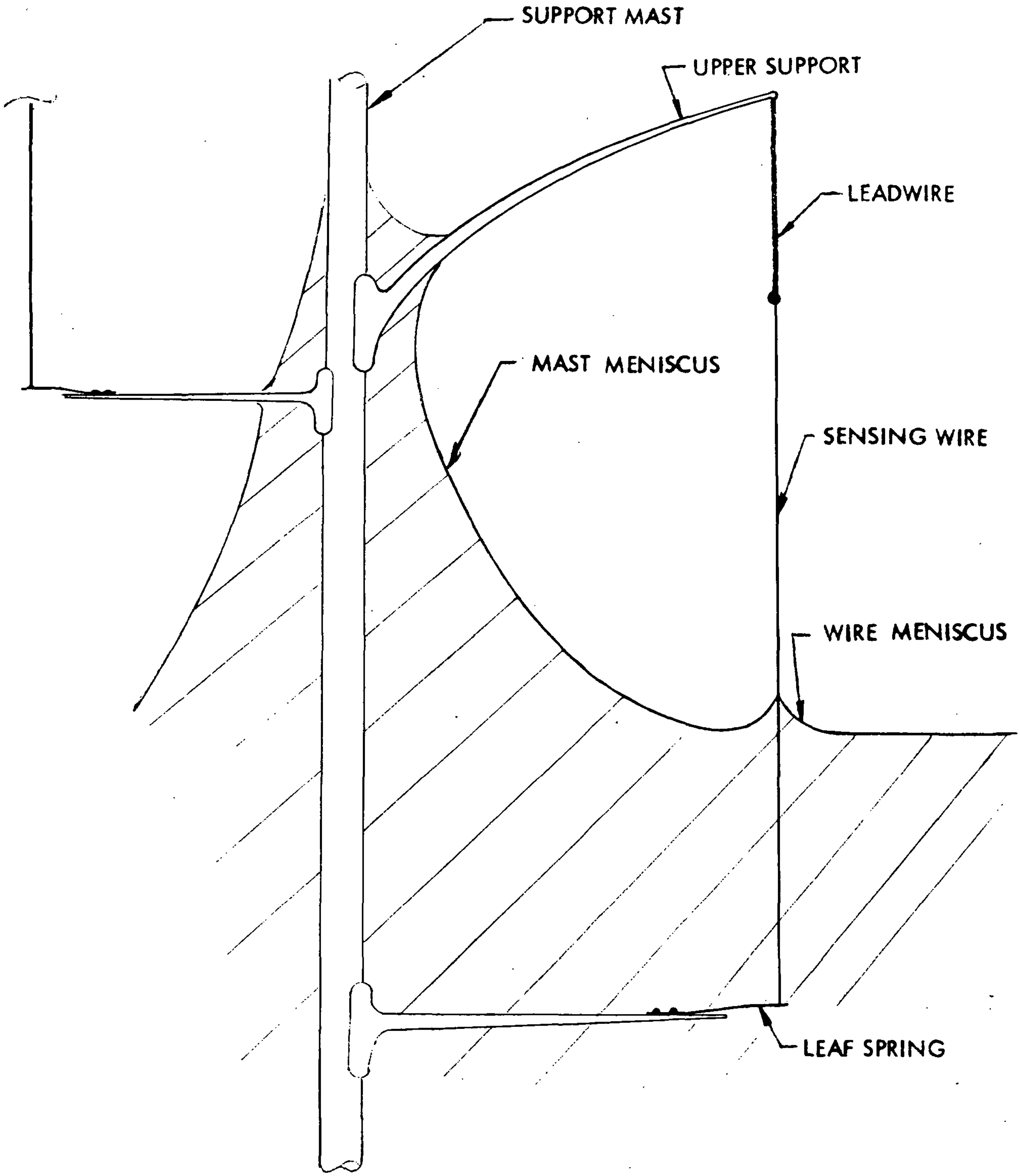


Figure 6.2.1-1 Vertical Resistance Wire Gauging System Configuration

Selection of the baseline design for the liquid/vapor interface control propulsion system for logistic operations requires evaluation of several possible design options. The major alternatives considered are summarized as follows: user vehicle or logistic tank mounted thrusters, existing attitude propulsion systems (APS) or new propulsion systems and thrusters, single or multiple thrusters, and propellant selection among cold gas, storable monopropellant, storable bipropellant, and LO_2/LH_2. The significant considerations involving these options are presented in the following paragraphs:

The propellant transfer propulsion system operational requirements developed for the ISPLS study are:

	TUG	CIS	RNS
Continuous Thrust (hrs)	10	15	10
Design Life (missions)	50	10	10
Total Life Requirements (hrs)	500	2850	1000
Minimum Acceleration (g)	10^{-4}	10^{-5}	10^{-5}
Thrust Level (lbs)	7.5	11.0	3.8

At the present time, most operational thrusters have a demonstrated firing life of less than one hour and in most cases only a few minutes. Some exceptions exist such as a 16-hour demonstration test conducted on a small hydrazine monopropellant thruster using test facility tankage and plumbing. Other low thrust (millipound level) systems have the potential of unlimited life, but in the thrust range under consideration here, highly qualified systems are not yet available. Apollo N_2O_4/MMH and N_2O_4/A-50 bipropellant reaction control systems have been run continuously for up to six hours, and on a cumulative life basis up to 12 hours. The projected life capability of advanced LO_2/LH_2 systems has been predicted to be about 1000 hours based on tests conducted under a NASA-LeRC contract (NAS3-14352). This is insufficient to fill the 2850 hours (unattended) requirements noted above.

Since the logistic tank module returns to earth with the orbiter after each in-orbit transfer operation, the opportunity exists for frequent maintenance of any systems installed in the module assembly, if required. If the propulsion system used for propellant transfer operations is placed on the user vehicles, the maintenance-free life requirement is extremely high.

Based upon the above requirements, it is concluded that insufficient extended life data exist on propulsion components to risk installation of the propulsion systems for liquid/vapor interface control on the user vehicles. It also follows that this propulsion system function should not be combined with the existing user vehicles APS for the same reason.

Selection of the propellant logistic propulsion system generic type was given consideration in the study. The systems analyzed were cryogenic bipropellant,

monopropellant, earth storage bipropellant, electrolysis, and cold gas. System descriptions, advantages and disadvantages and discussion are presented for each system in the following paragraphs:

Electrolysis System

Gaseous propellants are produced by the electrolysis of some suitable liquid such as water. As can be seen on Figure 6.2.2-1, the system contains an electrolytic cell, as part of the electrolysis unit. On the application of voltage to the electrodes in this cell, gas is generated and regulated to provide constant pressures at the thrusters. The gases are ignited to provide propulsive forces.

Advantages	Disadvantages
a. If power and water available, can be useful	a. High power requirements (24 watts/ millipound thrust)
b. I_{sp} = 350 sec	b. Explosion hazard
c. Simple system	c. Because of (a), required thrust levels impractical unless surplus of power and water exist.

Electrolysis was eliminated from further consideration in the ISPLS study due to its excessive power requirements.

Earth Storable Bipropellant System

Two liquids, an oxidizer and a fuel are pressure fed (or pump fed) through regulators and orifices into an engine to provide thrusting impulse. The propellants are ignited in the engine by an external source or hypergolically, such as is the case with N_2O_4 and MMH. The propellants are kept isolated until mixed in the thrust chamber. Bipropellant systems can be gaseous, cryogenic liquids, or storabe liquids. Figure 6.2.2-2 represents a typical earth-storable bipropellant system.

Advantages	Disadvantages
a. I_{sp} = 290 sec	a. Thermal control required
b. Pressure fed	b. Relatively large number of components
c. Minimal development risk	c. Complex
	d. Potential plume problems

The candidate propellant is N_2O_4 - MMH since it provides one of the higher performance systems with several qualified, space-rated and man-rated systems currently operational on Apollo, Mariner, and the Minuteman Post Boost Propulsion system. The thrust levels vary from one pound to several hundred thousand pounds.

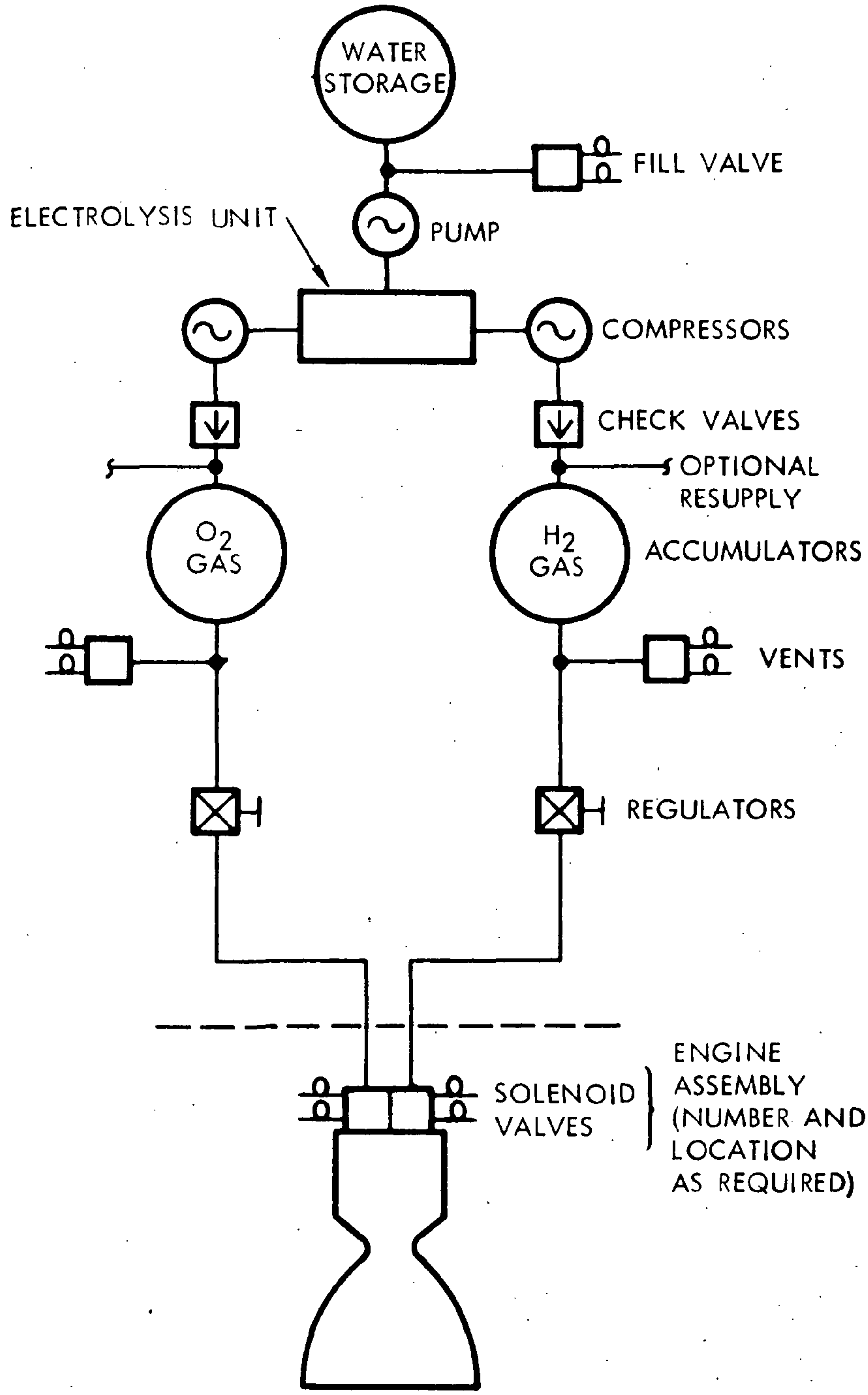


Figure 6.2.2-1 Typical Electrolysis System Schematic

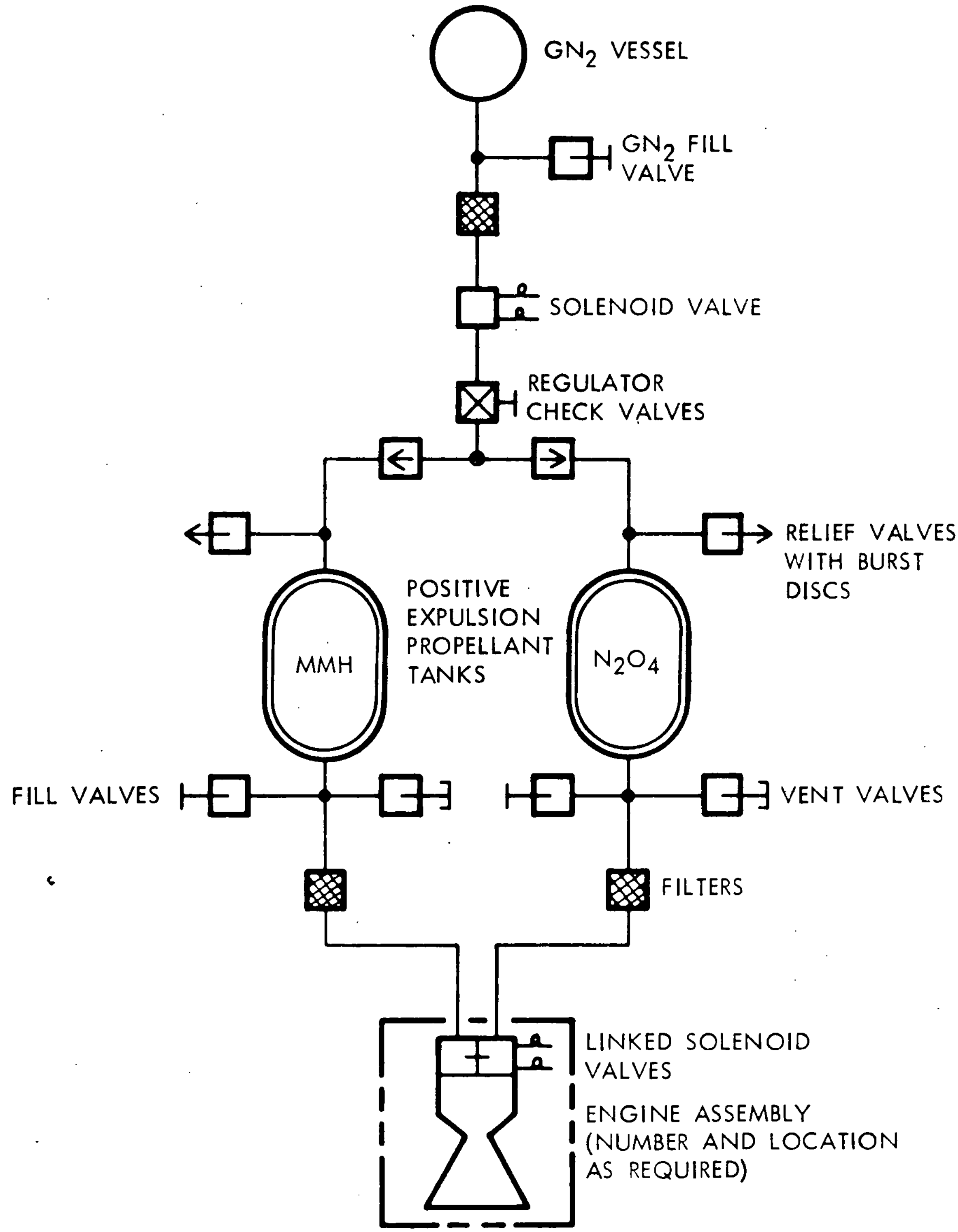


Figure 6.2.2-2 Typical Earth Storable Bipropellant System Schematic

Cryogenic Bipropellant System

The propellants are stored cryogenics (i.e., LO_2 and LH_2) which are isolated at low pressure. Figure 6.2.2-3 presents a schematic of a typical system. The engines operate from two accumulators, one of which stores GH_2, the other GO_2. When the system is activated, GH_2 and GO_2 flow to the engines and the gas generators where they are ignited. The gas generators drive the turbopump and provide heat to vaporize the pumped cryogenics which are stored in the accumulators. The system "bootstraps" and is self-propagating. The system shuts down when the gas supply is shut off.

Advantages	Disadvantages
a. High I_{sp} = 400 sec	a. Thermal leaks
b. Clean Plume	b. Complex
c. Low pressure propellant tanks	c. Major development issue; pumps and low thrust systems
d. Minimize logistics	d. Small thruster systems not yet developed

The LOX-LH_2 concept was selected as the baseline system because of its high performance using the primary propellants of the logistics module. Also since LOX-LH_2 systems are presently baselined for attitude control propulsion system applications on the space-based tug, the CIS, and the RNS, many of the system components can be common. Although no small LOX-LH_2 thrusters are in present use, the main propulsion systems of the upper stages of the Saturn V vehicle have adequately demonstrated the concept. Recent development effort has been initiated on low (20-100 lb) thrust level units.

Monopropellant System

A single propellant is used to provide the impulse of the entire system. Figure 6.2.2-4 presents a schematic of a typical system. The propellant is decomposed thermally or catalytically. Hydrazine, which has a good performance, is used for the description. The hydrazine (N_2H_4) decomposes to NH_3 and N_2. The highest performance is obtained when disassociation of the NH_3 is minimized. In a hydrazine system, the catalyst is usually contained in the thrusters where the N_2H_4 flows through the catalyst bed. This is an exothermal reaction providing low molecular weight gases. Some of the NH_3 is further decomposed to N_2 and H_2; this is an endothermic reaction which degrades performance.

Advantages	Disadvantages
a. Single propellant	a. Low performance
b. "Clean" plume	b. Catalyst limitation and cost
c. Pressure fed	c. Freezes at + 35° F
d. Simple	

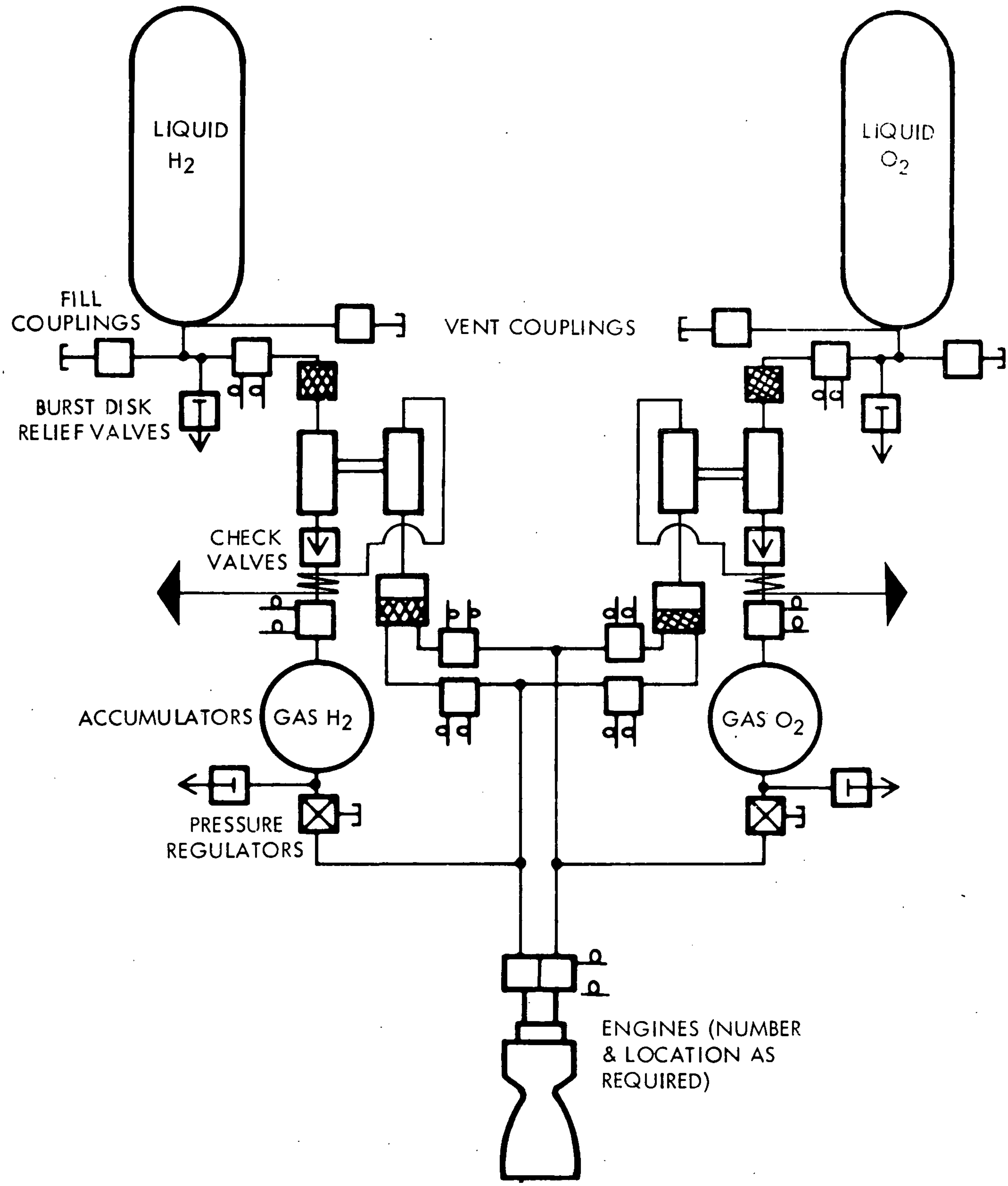


Figure 6.2.2-3 Cryogenic Oxygen-Hydrogen System Schematic

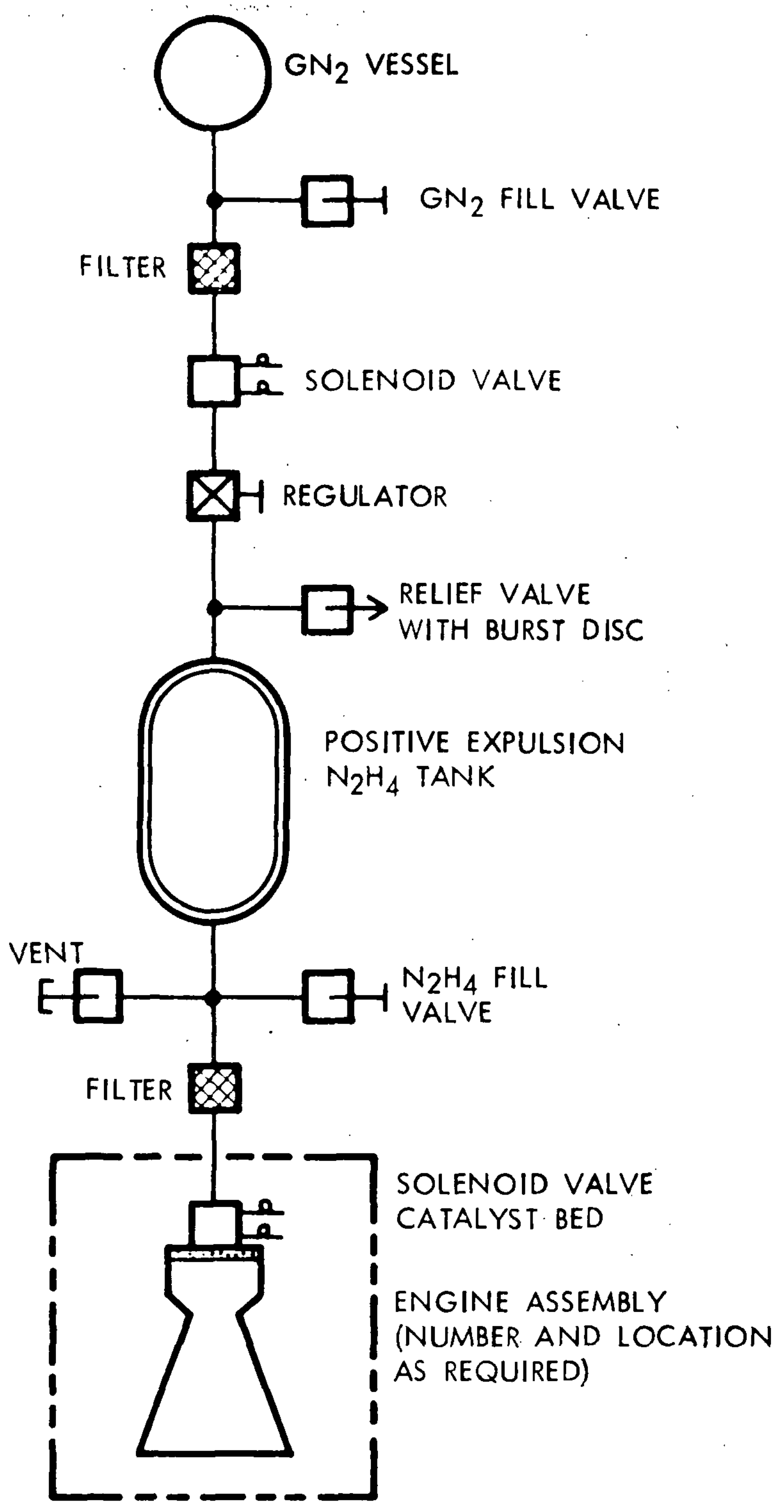


Figure 6.2.2-4 Typical Monopropellant System Schematic

The hydrazine system was selected for this trade due to the high performance and the fact that several systems are flight qualified and are operational on programs such as Intelsat, Transtage, Viking, Comsat and Mariner. Thrust levels vary from 10^{-4} pounds to about 1500 pounds on development articles.

Cold Gas System

A stored gas is used as the propellant for the mass expulsion system. The gas is usually stored at very high pressure for maximum quantity in as small a volume as possible due to the low performance. A typical system is shown in Figure 6.2.2-5. The lower molecular weight gas has the higher performance, but because of the low density, the tanks become very large and the system gets very heavy. The effective I_{sp} is the deliverable performance based on overall system efficiency. Cold gas systems are usually only considered for low total impulse requirements.

Advantages	Disadvantages
a. Simple	a. Usually very heavy
b. High Reliability	b. Low I_{sp} 275 seconds possible at ambient temperature. Usually only good for low I_T
c. No performance degradation in pulse mode	c. Requires heating to get the higher performance
d. No ignition or mixing problems	

The use of the boiloff hydrogen, a waste product of the logistic module as well as the user vehicles, was investigated as a cold gas thrusting system. This concept was found unattractive due to the low performance (I_{sp}), uncertain quantity of gas available for this purpose and the overall system complexity due to the possible need for such items as heat exchangers or backup gas generators.

The results of the propellant transfer propulsion system analysis are discussed in detail in Section 7.0 of Volume III.

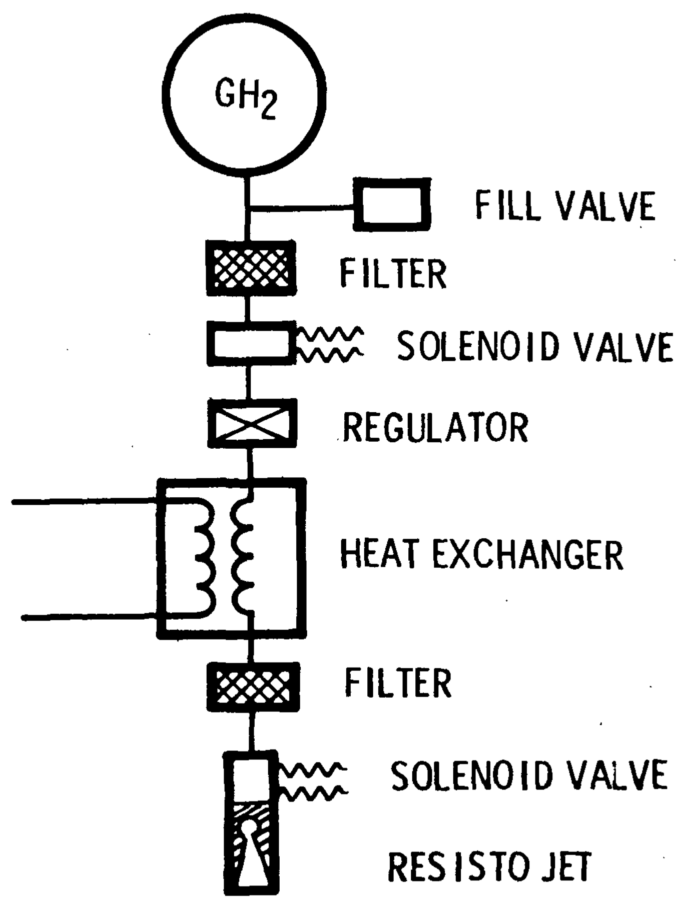


Figure 6.2.2-5 Typical Cold Gas System Schematic

7.0 PROPELLANT LOGISTIC CONCEPT SELECTION

This section of the report evaluates in terms of cost and other factors the various logistic concepts and modes of operation for conducting the scientific payload placement missions and the CIS/RNS missions in the program levels defined in accordance with the traffic models and operational concepts described in earlier sections of the report.

The analysis resulted in the selection of operational concept No. 2, which employs the space-based tug operating in a self-storage mode, as the baseline concept for performance of the scientific payload placement missions. A depot would not be required for either the tug or the CIS/RNS vehicles. The method of conducting the tug missions would not directly influence the operation of the CIS or RNS in their lunar missions except for possible commonality of equipment. Consequently the analysis and selection of tug mission concepts was conducted separately from the analysis of CIS/RNS missions.

The first question examined was the cost of delivery of propellant to space by various candidate methods. These included direct delivery by the shuttle with a propellant logistic tank in its cargo bay, delivery by the shuttle in conjunction with a space-based tug, and delivery by the use of the shuttle booster with an expendable second stage (ESS). The analysis indicated that to 180 n mi altitude, which was the selected parking orbit altitude for the depot, tug and the CIS/RNS, delivery by the shuttle alone is the most economical method and this was selected as the desired mode for use throughout the study.

A second question which was examined very early in the study was the need for a large depot to support the CIS or the RNS. If such a depot were required, it would be very large and could also support the tug in its scientific payload placement missions. It would then influence the whole course of the analysis for these missions. However, no requirement was found for a large depot for either the CIS or the RNS.

When it was determined that large depots were not required for CIS or for RNS, the question of a small depot to support the tug scientific payload placement missions was examined. The analysis indicated that failure to use the full payload capability of the shuttle on each flight would be very uneconomical. Propellant weight and scientific payload varied widely among the placement missions. The payload and propellant requirements for many missions would not fill the shuttle payload capacity and other missions would require two shuttle flights so that for space-based operation some form of in-space propellant storage was required to economically use the shuttle on each flight and thereby reduce the total number of shuttle flights. Accordingly, "mini-depots" were defined and incorporated into the seven logistics concepts for the scientific payload placement missions along with the other potential forms of storage including self storage in the tug and the use of two tugs. The latter portions of the analysis are concerned with the evaluation of the seven candidate logistics concepts for performing the missions in the five program levels.

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7.1 LOGISTICS AND STORAGE CONFIGURATIONS

7.1.1 Propellant Delivery Modes

Details of the Propellant Delivery Mode Study are presented in Section 2.0 of Volume III, Trade Studies. The results of the study are summarized here. The objective of the study was to determine on a dollars per pound basis the most economical method of delivering propellant to space considering the alternatives of shuttle alone, the shuttle with tug as a second stage and the shuttle booster with an expendable second stage. The results of the study are summarized in Table 7.1.1-1 wherein $178 per pound is indicated as the cost for the delivery of oxygen and hydrogen propellant to space up to an altitude of about 180 nautical miles. This is cheaper than the use of either shuttle with the tug or the shuttle booster/ESS combination.

The altitude of 180 nautical miles is selected because this is the indicated parking orbit altitude for both a CIS and a space-based tug. (See Trade Studies, Volume III, Section 3.0). The latest performance data on the proposed shuttle (as of February 15, 1972) indicates that the shuttle orbiter can carry a payload of 65,000 pounds to an altitude of slightly more than 180 nautical miles in the easterly launches on which the present calculations are based. For the present study, a 65,000 pound payload has been taken as the maximum payload which can be carried in the shuttle cargo bay.

The constant cost for delivery of propellant by the shuttle to both 100 nautical miles and 180 nautical miles results from the limitation of the cargo bay payload to 65,000 pounds. When the shuttle reaches orbit (100 nautical miles), it has sufficient maneuvering propellant aboard to deliver the full 65,000 pounds to 180 nautical miles. If more than 65,000 pounds were carried in the cargo bay with a corresponding off-loading of maneuvering propellant, the delivery costs to 100 nautical miles would be somewhat less.

In the shuttle plus tug case, it is assumed that the shuttle delivers the cargo to 100 nautical miles and the tug transfers it from 100 nautical miles to 180 nautical miles. Here the cost of flying the tug is added to the costs and the propellant used by the tug is subtracted from the propellant delivered. The shuttle plus tug mode becomes cheaper than the shuttle direct mode as the altitude of delivery increases beyond the capability of the shuttle to deliver its full payload. In the calculation of propellant delivered, an allowance for tank weights has been made and an allowance of 5 percent propellant transfer loss has been used for all cases.

The data for the booster/ESS has been derived from the NR study of this concept which was conducted as an extension of the Phase B Shuttle Contract. The study was based on the use of a B9U flyback booster and the conceptual development of an expendable second stage employing orbiter engines to place a maximum payload weight into space.

The data have been updated to reflect the cost per flight of the newer booster configuration. However, the payload capability has not been significantly changed by the new configurations. The data indicate that the use of the expendable second stage is not economical for propellant delivery.

Table 7.1.1-1 Propellant Delivery Costs

	Oxygen/Hydrogen Tug/CIS Supportive		Hydrogen RNS Supportive		Hydrogen With External Shuttle Tanks	
Delivery Mode	Prop. Del. K lbs	Dollars Per Pound	Prop. Del. K lbs	Dollars Per Pound	Prop. Del. K lbs	Dollars Per Pound
Shuttle Direct:						
100 n mi	56.9	$178	32.3	$314	49.4	$235
180 n mi	56.9	$178	32.3	$314	49.4	$235
Shuttle plus Tug to:						
180 n mi	54.4	$210	31.6	$363		
Booster/ESS to:						
100 n mi	180.5	$238	183.5	$229		
180 n mi	175.0	$245	177.8	$237		
Booster/ESS plus Tug to:						
180 n mi	170.0	$256	175.8	$247		

Although the indicated payload capability is better than three times that of the orbiter after allowance for tank weight and propellant losses, the cost of expending the stage is too great to off-set the advantage of the greater payload. The data simply illustrate the need and reason for developing a reusable vehicle as opposed to an expendable vehicle.

In the case of the delivery of hydrogen alone for the RNS supportive cases, the orbiter cargo bay is volume limited and can carry a net hydrogen payload of only about 32,000 pounds. In this case, the cost of delivery of hydrogen propellant with the shuttle orbiter direct exceeds that for the booster/ESS. The propellant tank on the ESS is not volume limited and can carry a full payload weight. Analysis indicates that the capability of the shuttle to carry hydrogen could be augmented by external tanks which could take several forms. An allowance made for weight and cost of this approach and the resulting increase in payload indicates that the orbiter could be made competitive with the booster/ESS for hydrogen delivery by this means.

It should be noted that the cost of development of an ESS is not included in the costs presented in the Table 7.1.1-1. Development of the propellant payload tank used with the ESS is not included. If an ESS were developed for the purpose of propellant delivery alone and its costs included, the delivery costs would be correspondingly increased.

7.1.2 CIS/RNS Depot Requirement

A study was conducted to determine the requirement for a depot to support the CIS vehicle in flights to the moon. This study is documented in Section 4.0 of Volume III. No justification was found for the necessarily large and expensive depot which would be required to support a CIS. The study indicates, however, that there would be a need for some form of in-space propellant storage to support CIS flights to the moon if the CIS flight rate were to be increased above that of the two flights per year used in the ISPLS program model and considered in the CIS vehicle contractual study which was conducted in parallel with the ISPLS study.

It was also indicated that this additional storage capability could be provided most economically by the use of a second CIS to be space-based and used in the lunar flights. This second vehicle, used for storing propellant and also used alternately in the lunar flights, could provide the same and additional advantages over the use of a depot and at lower cost. If only one CIS vehicle were space-based and used, consideration should be given to a depot if the flight rate were to reach 3 to 4 flights per year. The employment of two CIS's should certainly be considered if this flight rate were contemplated.

Extrapolation of the logic and results of the CIS analysis to the RNS case indicated the same general conclusions, namely, that no justification could be made for depot support, and that an indicated need for storage could better be achieved by the use of two RNS's. Because of the lesser propellant requirement for RNS than for CIS (about 300,000 pounds versus 1,000,000 pounds) and fewer number of shuttle flights to support it, there is less need for a depot to support RNS than CIS.

The CIS vehicle can accumulate and store its own propellant in space. Because these are the functions of a depot, there was considerable question at the outset of this study as to the need or purpose of a depot. However, about twenty shuttle flights are required to fill the baseline CIS as used in this study. With a two week turn around per shuttle flight, 40 weeks would be required to fill the CIS for each flight. To reduce this time period would require additional shuttles operating full time and dedicated to fueling the CIS. As the CIS flight frequency increases and the interval of time available between flights for fueling decreases, more dedicated shuttles are required.

The number of shuttles could be reduced by providing in-space storage either by a second CIS, alternating in flights to the moon, or by a depot which would be continually available to receive propellant and could transfer its propellant to the CIS in a short interval of time when the CIS returned from the moon. Figure 7.1.2-1 illustrates the cost saving in the purchase of shuttles made possible by providing a separate in-space propellant storage for a CIS over a five year period as a function of the frequency of flights of the CIS. Plotted on the figure is a band representing the five year program cost for a CIS supportive depot and a band representing the price of purchasing and placing a second CIS in space, which could provide, in addition to the advantages of a depot, other support to the entire lunar program. The figure indicates that an economic advantage would occur by the use of two space-based CIS's at the rate of two flights per year. More frequent rates should certainly consider this possibility.

7.1.3 Propellant Logistics Tank and Mini-Depot Options

The term "mini-depot" has been applied to the relatively small tug supportive depots with a capacity of about 60,000 pounds of propellant as opposed to the very large depots which would be required to support a CIS or an RNS. As described earlier, when it was determined in the course of the study that there was no requirement for a CIS/RNS supportive depot, the need for some form of storage to support a space-based tug alone in performing the scientific payload placement missions was examined. The use of the propellant logistics tank, which is to be carried in the cargo bay of the shuttle, as a part of the mini-depot, was given consideration as well as other options. The options considered are presented in Figure 7.1.3-1.

The logistics tank from the shuttle cargo bay could not be used as an in-space propellant storage device unless equipment were added to it to permit it to fly as a free space vehicle and so that other vehicles could rendezvous and dock with it. This equipment would include altitude control, attitude reference, communication and control, and rendezvous and docking equipment. It was conceived that such equipment could be housed in an "equipment module" sized to be carried in the shuttle cargo bay and to which the logistics tank could be attached modularly as the propellant storage portion of the mini-depot.

A tug would dock with the mini-depot and propellant would be transferred to the tug by a fluid transfer process. When empty, the logistics tank would be replaced, modularly, by a full tank brought up in the shuttle.

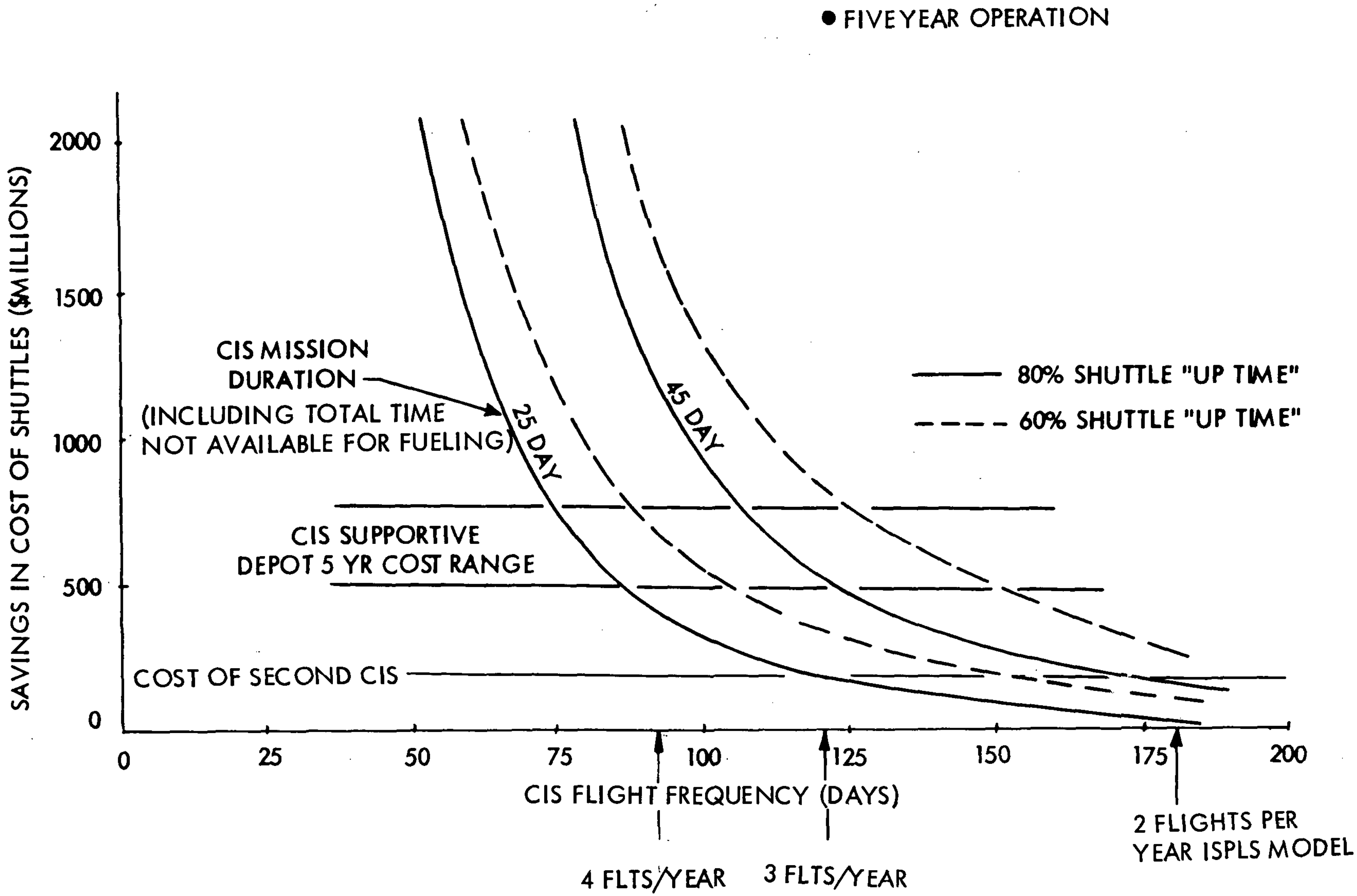
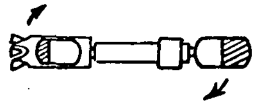


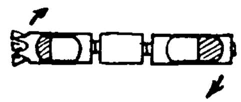
Figure 7.1.2-1 Savings in Shuttle Acquisition Costs by CIS Operation with Depot or Second CIS

1. MODULAR MINI-DEPOT (MODULAR TANK TO DEPOT, FLUID OUT)

A. ROTATIONAL SETTLING - - - -  DEPOT EQUIP MOD + LOGISTIC/STORAGE TANK

B. LINEAR SETTLING - - - - -  DEPOT EQUIP MOD + LOGISTIC/STORAGE TANK

2. PERMANENT TANKAGE MINI-DEPOT (FLUID IN, FLUID OUT)

A. ROTATIONAL SETTLING - - -  ONE TUG FILLING CAPACITY (LOG. TANK SIMILAR TO ABOVE)

B. LINEAR SETTLING - - - -  60' DEPOT INCLUDING TANKAGE (LOG. TANK SIMILAR TO ABOVE)

3. DIRECT TANK TO TUG TRANSFER (NO STORAGE IN TANK)

A. LINEAR SETTLING - - - - -  TRANSFER CAPABILITY TANK

B. POSITIVE EXPULSION - - -  TRANSFER CAPABILITY EXPULSION TANK

4. TUG TO TUG; LINEAR TRANSFER (TWO TUG)

A. TRANSFER CAPABILITY TUGS - -  DEFINE IMPACT TO BASELINE (TUG) (LOGISTIC TANK SIMILAR TO ABOVE ALSO REQD)

B. TUGS WITH TRANSFER MODULE -  DEFINE IMPACT TO TUG & DEFINE TRANS MOD (LOGISTIC TANK SIMILAR TO ABOVE ALSO REQD)

Figure 7.1.3-1 Propellant Logistics Options Supporting Space Based Tug

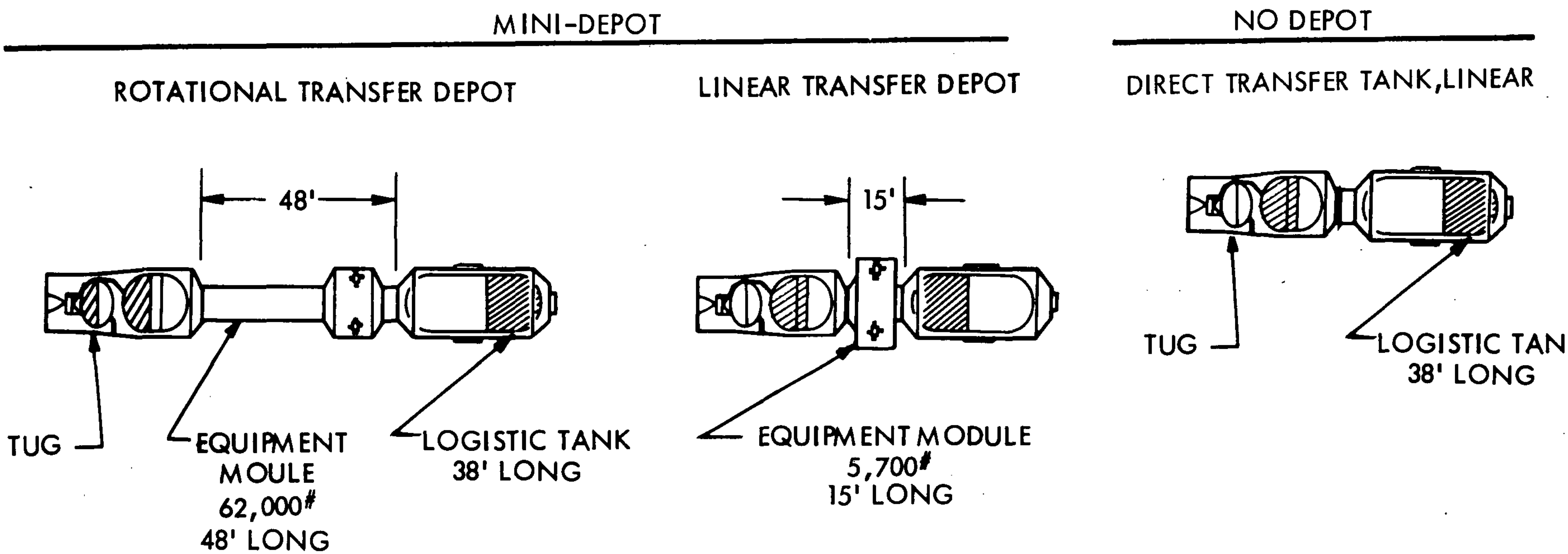
This concept is illustrated in 1A and 1B of Figure 7.1.3-1 and in Figure 7.1.3-2. In the rotational settling version, a structural boom was added to the equipment module to separate the tug from the logistics tank so that the c.g. would not enter either tank during the propellant transfer operation. The c.g. analysis showed that the boom would need to be more than 100 feet long for this purpose. The length of the equipment module and boom in the rotational case was shortened to 48 feet by adding ballast so that the total weight of the equipment module and boom is 62,000 pounds. The required equipment and housing itself weighed 5,700 pounds. This sizing would permit the equipment module with boom to be carried in the cargo bay of the shuttle.

Other options considered and illustrated in Figure 7.1.3-1 included the permanent tank cases 2A and B, wherein the storage tank would remain in space with the equipment module as a part of the mini-depot. Propellant brought up in the shuttle cargo bay tank would be transferred to the mini-depot tank by a fluid transfer process. An advantage of this approach was that the mini-depot storage tank could be initially carried in the shuttle bay empty and could be nearly 60 feet long thereby providing additional storage capacity. It could also be designed without the requirement for transfer into and out of the earth's atmosphere when filled with propellant. This fixed tank version was eliminated from the candidate concepts at an early date. It required two fluid propellant transfers with associated losses, one from the shuttle tank to the mini-depot tank and again from the mini-depot to the user vehicle. It would require an additional development cost. The shuttle cargo bay logistics tank requires design and development in any case. If additional storage capacity were required, two or three shuttle bay logistics tanks could be ganged together attached to the equipment module.

The modular mini-depot, the direct transfer concept, and the two tug concepts (Figure 7.1.3-1) were retained in the study and incorporated into the candidate space-based logistics concepts for evaluation in the conduct of all the scientific payload placement missions in the program. These are evaluated in the subsequent sections of the report. The direct transfer concept was the concept finally selected. The method of transfer within each of the options, (linear versus rotational settling and positive expulsion) were evaluated later in the study. (See Volume III, Section 6.)

Program cost estimates, including development, production and operations, were prepared for both the equipment module and the tanks to be used in the subsequent evaluation studies. The data associated with the linear version was used in the overall concept evaluations. These costs are presented in Figures 7.1.3-2 and 7.1.3-3. Additional details on mini-depot definition and costing are contained in Section 5.0 of Volume III.

Three versions of the logistics tank were used in the initial evaluation studies. These are illustrated in Figure 7.1.3-3. Later more detailed versions of these tanks and associated cost development are contained in Section 9.0. The tug or CIS supportive oxygen/hydrogen tank module is 38 feet long and would hold about 60,000 pounds of propellant. This allows 22 feet to be employed for the scientific payload in the shuttle cargo bay. The median length of scientific payloads in Program Level C is 12 feet. The median weight of scientific payloads is 1000 pounds so that a small off-loading of the tank is required to accommodate the payload when they are carried together.



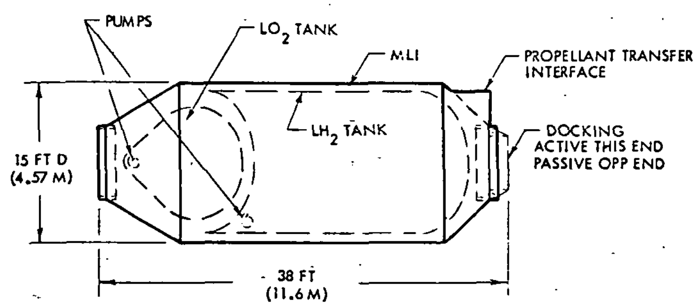
EQUIPMENT MODULE COSTS	ROTATIONAL	LINEAR
DEVELOPMENT	\$ 98.9 $\overline{M}$	\$ 90.2 $\overline{M}$
PRODUCTION (1 MODULE)	14.5	13.4
MAINTENANCE *	43.6	25.0
	\$ 157.0 $\overline{M}$	\$ 128.6 $\overline{M}$

TANK COSTS	ROTATIONAL/LINEAR	DIRECT TRANSFER
DEVELOPMENT	\$23.8 M	\$26.5 M
PRODUCTION (5 TANKS)	12.6	14.3
MAINTENANCE	10.7	12.1
	47.1	52.9

* ASSUME 6 YR LIFE.
BROUGHT TO EARTH
TWICE FOR MAINTENANCE

Figure 7.1.3-2 Mini-Depot and Logistic Tank Concepts

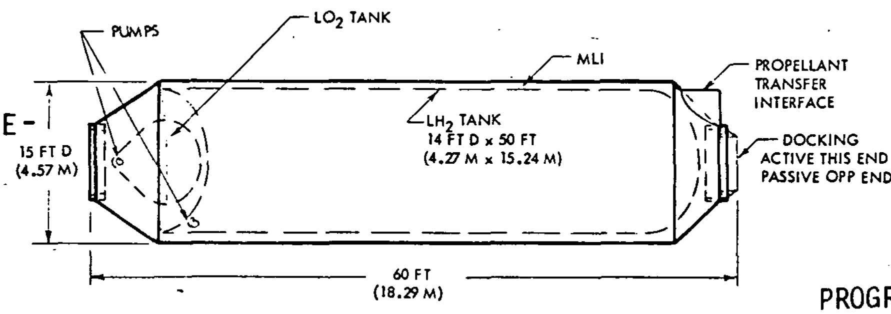
CIS SUPPORTIVE-WEIGHT LIMITED LO_2/LH_2



WEIGHT	
EMPTY	5,100#
LH_2	9,500
LO_2	50,400
	65,000

PROGRAM COST* $53M

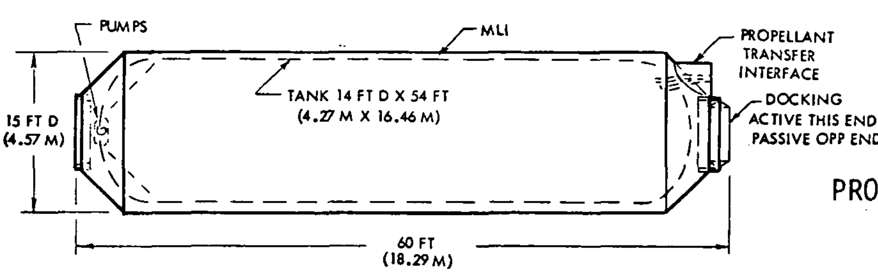
RNS SUPPORTIVE-VOLUME LIMITED LO_2/LH_2 1:2



EMPTY	8,700#
LH_2	32,000
LO_2	15,700
	56,400

PROGRAM COST* $85M

ALL HYDROGEN-VOLUME LIMITED



EMPTY	7,000#
LH_2	34,000
	41,000

PROGRAM COST* $65M

*DEVELOPMENT, 5 TANK PRODUCTION, OPERATION AND MAINTENANCE

Figure 7.1.3-3 Propellant Logistic Tanks

The all-hydrogen version and nearly-all-hydrogen versions of the tanks shown in Figure 7.1.3-3 were defined to support the RNS evaluations. For both the CIS and RNS, it was conceived in the initial evaluations that a direct transfer mode from tank to CIS with linear acceleration for propellant settling would be employed. The length of a boom which would be required for rotational settling would need to be several hundred feet long.

7.2 COST ANALYSIS AND SELECTION

This section covers the development of the logistics program costs for Program Levels A through E operating under the candidate logistics concepts. For the scientific payload placement missions employing a tug or other payload propulsive stage (PPS), the candidate concepts include the five space-based concepts and the two ground-based concepts described in Section 4.0. The primary objective was to determine which is the most economical operational concept. The space-based concepts include: no storage, one tug with self storage, two tugs with self storage, and one tug with mini depot storage. The fifth concept operates under the ground rule that scientific payload and propellant can never be carried together in the same shuttle. This proves to be very expensive.

Among the space-based concepts, the single tug self-storage mode (No. 2) was selected as the most economical. The data indicate a significant cost savings for the storage modes as opposed to the no-storage mode by reducing the number of shuttle flights required to conduct the total logistic programs. The capacity of in-space storage required, however, is no greater than that which can be held by a single tug in a self-storage mode so that no need is indicated for the additional expense of a mini-depot.

A total logistics program which employs the reusable ground-based tug is slightly cheaper than the space-based concept, No. 2, employing the space-based tug in the self-storage mode. The space-based tug used in the study, however, is a relatively heavy and expensive vehicle (with four engines and separable intelligence module) compared with the ground-based tug. In the sensitivity studies presented in Section 8.0, comparisons are made with a lighter weight tug and it is shown that the difference in costs of ground versus space-based tug are due to the tug characteristics and could be eliminated by the use of a lighter weight tug.

For the lunar missions employing the CIS/RNS, the logistic program costs are developed for two modes of operation (Mode 1 and Mode 2) for the CIS and RNS vehicles baselined in the ISPLS study.

7.2.1 Costing Approach and Ground Rules

Costing ground rules as developed in the early phases of the study for the development of logistic program costs are as follows.

a. Costs shall be developed at 1971 dollars.

b. Rough orders of magnitude (ROM) costs will be used.

c. Costs will be derived from existing studies and programs wherever possible; e.g., shuttle, tugs, etc.

d. Costs will be developed for new equipment and modifications required for the propellant logistics operations; e.g., depots, logistic tank, etc.

e. Development costs as well as production and operation costs are to be included only for the dedicated propellant logistic hardware, Item d.

f. Development costs will not be included for vehicles and hardware which would exist for other purposes than propellant logistics. Production costs as well as operation costs for shuttle, tug, and other vehicles in this category will be prorated on a unit cost per flight basis.

g. Propellant logistic program costs developed for Program Levels A through E will include delivery system costs only. They will include vehicle costs as well as the propellant used. They will exclude payload costs; i.e., the costs of experiments and scientific payloads placed in orbit.

The overall propellant logistic program costing procedure is illustrated in Figure 7.2.1-1. The "dollars per pound" delivery mode costs in the bottom portion of the figure are presented in Section 7.1.1. The logistic program costs include the cost of propellant and payloads delivered to space by calculating the purchase (production) costs and operations costs of the vehicles employed on a per flight basis. As stated in the ground rules, development costs are included only for dedicated hardware such as depots and tanks. Prorated production costs, maintenance and the initial cost of placing the vehicles in space are included for all tug and PPS flights. It is necessary to include the prorated vehicle production costs as well as propellant used in the propellant logistic program costs for several reasons. In the case of the shuttle, more than the currently planned initial acquisition of five shuttles would be required to accomplish Program Levels D and E including the CIS/RNS so that it is necessary to reflect the purchase cost of additional shuttles. Comparisons are also made with logistic concepts employing expendable vehicles such as shuttle booster with expendable second stage and the Centaur, Agena, and FW-4S. In these cases it is, of course, necessary to include vehicle production costs.

7.2.2 Cost of System Elements

7.2.2.1 Shuttle Costs

The space shuttle, as the primary vehicle for delivery of propellant to space, is one of the principal cost elements in the propellant logistic cost program. The shuttle design concept progressed through several versions during the course of the ISPLS study. Initially the study was baselined to the North American/General Dynamics 161 C shuttle (without drop tank) and the B9U flyback booster, Figure 7.2.2-1. As of February 15, 1972 the drop tank shuttle with pressure fed booster was adopted as the ISPLS baseline and all costs were recalculated on the basis of this vehicle. Subsequently, the solid rocket motor (SRM) booster operated with recovery and refurbishment of the casings has been identified as the selected version. Costs per flight for the pressure fed recoverable booster version were calculated in accord with the ISPLS program ground rules as shown in Table 7.2.2-1. The costs were derived from the shuttle program under study by NR under Contract No. NAS9-10960 (Case 5113 as of 2/15/72).

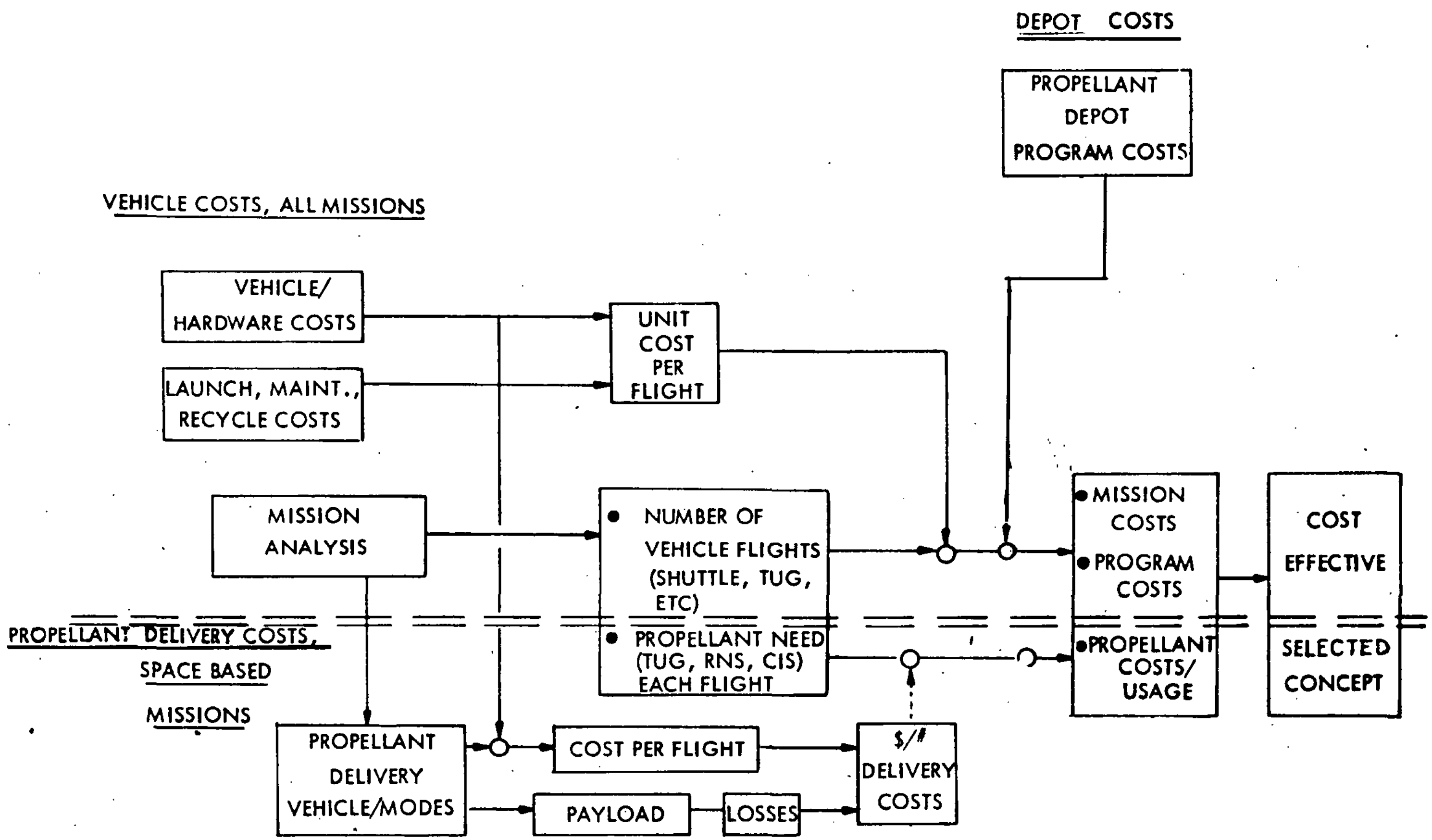
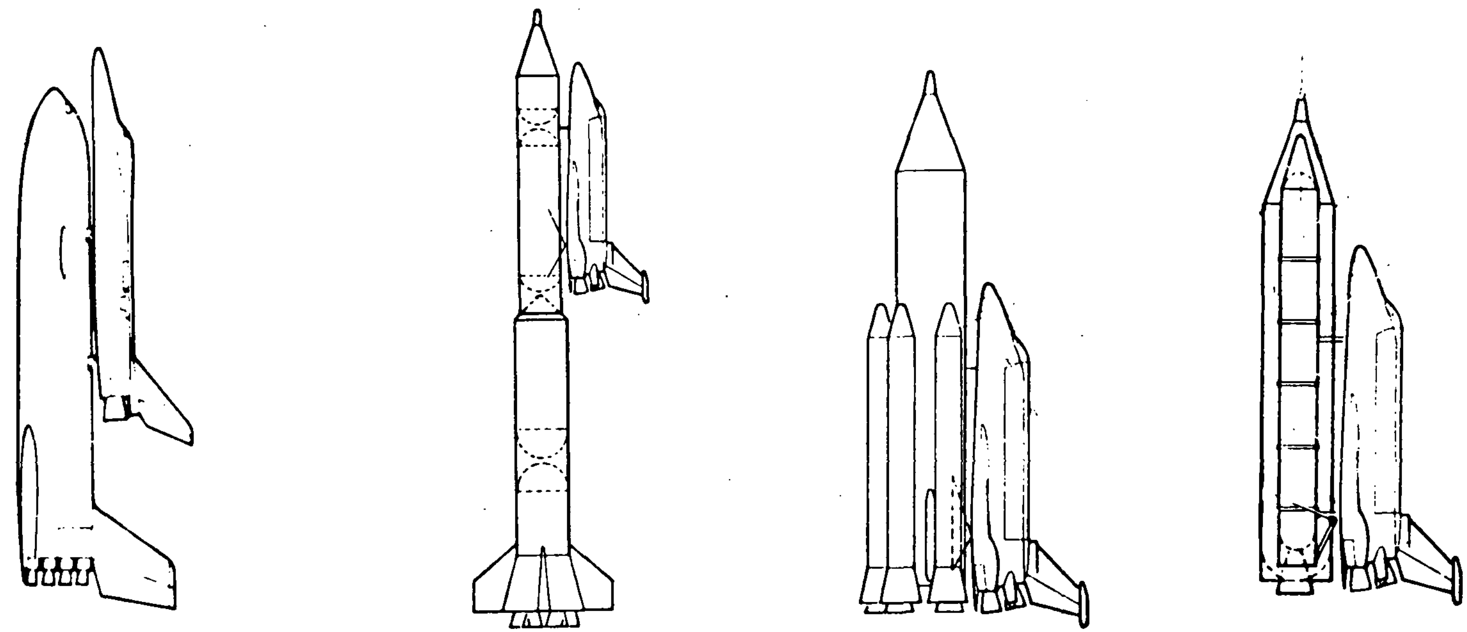


Figure 7.2.1-1 Program Costing Procedure



AVERAGE COST PER FLIGHT*

FLYBACK BOOSTER		\$5.7 M
PRESSURE FED BOOSTER		10.2
SOLID ROCKET MOTOR (SRM)		
NOT RECOVERABLE	≈	14.0
RECOVERABLE	≈	9.0

\$ 10 M PER FLIGHT USED IN CURRENT ISPLS STUDY

*INCLUDES ORBITER AND BOOSTER PRODUCTION COSTS PRORATED ON 444 FLIGHTS

Figure 7.2.2-1 Shuttle Costs per Flight

Table 7.2.2-1. Shuttle Costs Per Flight

Shuttle Program	Program Costs	
10 years	Development	$ 4.6 billion
444 operational launches	Production	2.2
5 orbiters	Operations*	2.3
10 boosters		$ 9.1 billion
Amortized Program Costs for ISPLS Study		
Production costs	$2.2B/444 flights	$ 5.0 million
Operation costs	$2.3B/444 flights	5.2
		$10.2 million

* Operation includes: launch costs, maintenance/recycle costs, program spares, contractor/KSC costs

Cost estimates per flight of the earlier versions and the SRM version with and without recovery of the booster cases are shown calculated on a comparable basis in Figure 7.2.2-1. Although development costs decreased from earlier versions of the shuttle program, operations and production costs increased and must be reflected in the propellant logistic program costs. The costs associated with the SRM cases are very preliminary at this time and are changing as the shuttle studies continue. A figure of $10 million per shuttle flight has now been used throughout the ISPLS study and is considered as a representative figure which fairly represents shuttle costs per flight for the ISPLS study comparison. None of the major conclusions derived from the candidate logistic program cost comparisons were changed by the increase in shuttle flight costs during the course of the program.

7.2.2.2 Other Program Element Costs

Figure 7.2.2-2 contains the unit production costs for vehicles used in the study, which have been taken generally from other existing studies or, in the case of the propellant logistic tanks, developed elsewhere in the current study. The ground-based reusable tug cost is derived from the NR/Air Force contract for an Orbit-to-Orbit Shuttle (OOS) (Contract No. F04701-71-C-0171) which was in progress at the time of the ISPLS study. The space-based tug cost was derived from the NR/NASA contract for a reusable space-based tug. The space-based tug concept was developed under ground rules which resulted in a relatively expensive and heavy vehicle. It has provisions for attachment of a crew module, and is convertible to a moon lander. It has a separable intelligence module with quadruple electronics redundancy and it has four engines. A learning curve allowance for the required number of vehicles is made throughout the study. The data in the table is based on a buy of five vehicles. The mission lives are in general those used in the other studies

PROGRAM ELEMENT	AVERAGE UNIT PRODUCTION COST	MISSION LIFE	AVERAGE COST PER MISSION (1)
• GROUND BASED NON-REUSEABLE			
FW-4S	$ 0.2 M	1	$ 0.2 M
AGENA	3.0	1	3.2
CENTAUR	9.0	1	9.5
• GROUND BASED REUSEABLE TUG	17.2	36	1.4
• SPACE BASED TUG	38.1	50	1.3
• CIS	110.9	10	18.8
• RNS	47.1	10	19.7
• PROPELLANT LOGISTIC TANKS			
CIS LO_2/LH_2 WT. LIMITED, 38'	2.7	100	.11 (2)
RNS LH_2 VOLUME LIMITED, 60'	4.0	100	.13

(1) INC. VEHICLE, LAUNCH, & MAINT. COSTS. EXCLUDES PROPELLANT COSTS

(2) INCLUDES DEVELOPMENT COSTS PRORATED

Figure 7.2.2-2 Program Element Cost Summary

SD72-SA-0053-2

from which the costs are taken. In the case of the space-based tug the limiting factor on mission life is the engine operation.

The engine characteristics for the tug were derived from specifications prepared by the AF Rocket Lab for a new engine with a 600-minute operating life and a 300-engine start capability. These characteristics were equated with the average number of starts (4 to 6) and the average burn time (12 minutes) in the ISPLS Program Level C mission, which yielded the 50-mission life for the space-based tug.

The average costs per mission (Figure 7.2.2-2) include the prorated production costs and allowances for preparing the vehicles for launch, for maintenance and for initially placing the vehicles in space as applicable. In the case of the ground-based tug, 5 percent of production costs was allowed for recycle and launch preparation. In the case of the space-based tug it was assumed that the tug was returned to earth an average of once every ten missions during its 50-mission life for maintenance. The average cost per mission includes shuttle costs for returning the vehicle to earth and 10 percent of the purchase costs for repair and refurbishment of the vehicle for each return to earth.

CIS costs are taken from the S-II Interorbital Shuttle Capability Analysis Report, SD 71-248-8, April 24, 1971, Vol. 8, Configuration A, which was baselined for the ISPLS study. The RNS costs were taken from the Nuclear Flight System Definition Study, Phase III Final Report, SD 71-466-6, Vol. IV, April 1971. Both studies provided a two-vehicle program with 20 flights. Average costs per mission were calculated as follows:

<u>CIS Costs</u> - 2-CIS Program, 20 Flights

Production costs	\$ 222 M	
Launch costs	155 M	
	\$ 377 M	

$$\frac{\$\,377\text{ M}}{20\text{ flights}} = \$18.8\text{ M per flight}$$

<u>RNS Costs</u> - 2-RNS Program, 20 Flights

Production costs	\$ 94 M
Launch operations	300 M
	\$ 394 M

$$\frac{\$\,394\text{ M}}{20\text{ flights}} = \$19.7\text{ M per flight}$$

The CIS and RNS vehicles are space-based vehicles and the launch costs are the cost of initially placing them in space. The cost of delivering to space of the propellant used by the CIS/RNS is calculated in logistic program costing in terms of shuttle flight costs required to deliver the propellant, as is also done for the other vehicles.

The propellant logistic tanks (Figure 7.2.2-2) are those used in the cargo bay of the shuttle to deliver propellant to space. These are discussed in Section 7.1 above along with the mini-depot costs which are presented there. In the case of the logistic tanks, development as well as production costs are prorated over the assigned mission lives of the tanks.

7.2.3 Program Costs for Tug/PPS Missions

The objective of the logistic program costing is to evaluate alternate logistic operational concepts and determine the most economical mode of operation. The costs are developed in accordance with the ground rules and costing procedure described in Section 7.2.1 above. The logistic program costs are delivery system costs only. They include the prorated production costs of the vehicle hardware used. They also include the cost of the propellant used in terms of the cost of shuttle flights which are required to move the propellant into space.

In accordance with the program ground rules, the reusable tug, ground-based or space-based, would not be available until 1985 so that complete comparisons of all the candidate operational concepts employing these vehicles are made in the six-year portion of Program Levels A through E from 1985-1990. The combination of costs for this interval with the 1979-1984 interval and the addition of costs for the CIS/RNS missions are presented in later sections.

Figure 7.2.3-1 presents the comparative total logistic program costs for the scientific payload placement missions in Program Level C for the period from 1985-1990 operated under seven different logistic operational concepts. Figure 7.2.3-2 presents the buildup of the cost data in Figure 7.2.3-1.

7.2.3.1 Logistic Concepts Review

The seven operational concepts are described in Section 4.0, but are reviewed briefly here to indicate what was considered in the cost estimates. There are 157 scientific payloads in the program to be carried to space by the shuttle along with propellant and a tug or payload propulsive stage (PPS). The candidate concepts for accomplishing this are as follows.

a. Ground-Based Non-Reusable

The solid propellant kick stage (FW-4S derivative) or the Agena or Centaur are carried aloft with propellant and scientific payload by the shuttle and expended on the payload placement mission. For a given mission, the FW-4S is used if it has the performance capability, if not the Agena is used and if it has not the capability, then the Centaur is used. In some cases two Centaurs in tandem are used. This requires additional shuttle flights. It is assumed that an interstage structure is provided when two vehicles are used in tandem.

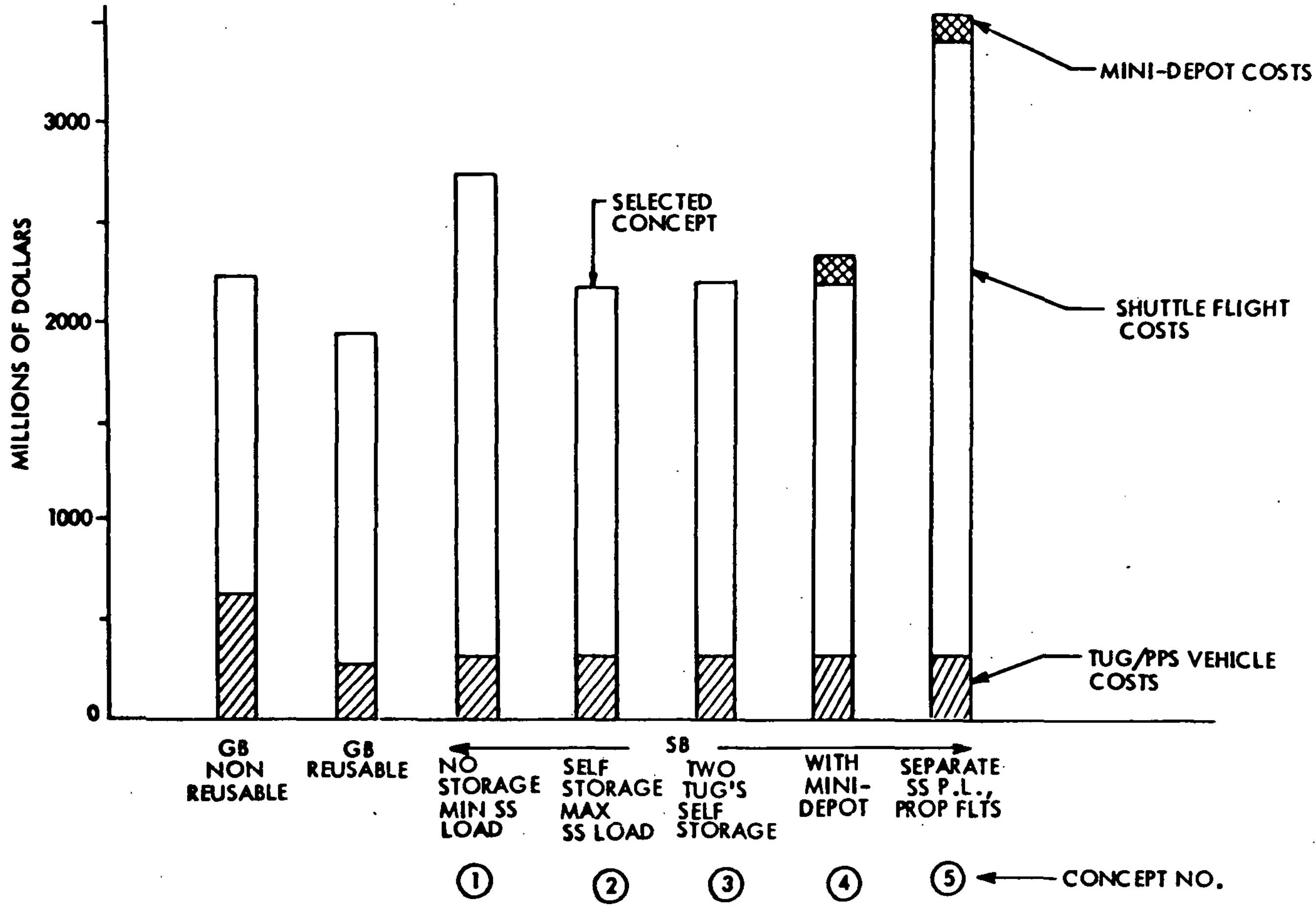


Figure 7.2.3-1 Logistic Program Cost Comparison
All Payload Placement Missions
Program Level C - 1985-1990

NON-REUSABLE PPS (FW-4S, AGENA, CENTAUR) 1985-1990

VEHICLES	COST PER FLT $M	NO. FLIGHTS	COST $M
FW-4S DERIVATIVE	.2	45	9
AGENA	3.2	98	314
SINGLE CENTAUR	9.5	7	67
TWO CENTAUR	19.0	7	133
TOTAL P.L. PLACEMENTS		157	—
SUPTG. SHUTTLE FLTS	10.0	167	1670
			2193

GB REUSABLE TUG 1985-1990

MISSIONS & VEHICLES	COST PER FLT $M	NO. FLIGHTS	COST $M
ONE GB TUG	1.4	147	206
TWO GB TUGS	2.8	6	17
GB TUG EXPENDED	15.0	4	60
TOTAL P.L. PLACEMENTS		157	—
SUPTG SHUTTLE FLTS	10.0	166	1660
			1943

SPACE BASED TUG BY OPERATIONAL CONCEPT 1985-1990

VEHICLES	COST PER FLT $M	① ONE TUG, NO STORAGE		② ONE TUG SELF STORAGE		③ TWO TUGS SELF STORAGE		④ ONE TUG WITH MINI-DEPOT		⑤ SEPARATE P.L., PROP SHUTTLE FLTS	
		NO. FLTS	COST $M	NO. FLTS	COST $M	NO. FLTS	COST $M	NO. FLTS	COST $M	NO. FLTS	COST $M
SINGLE SB TUG	1.3	147	191	147	191	147	191	147	191	147	191
TWO SB TUGS	2.6	6	16	6	16	6	16	6	16	6	16
SB TUG EXPENDED	28.0	4	112	4	112	4	112	4	112	4	112
TOTAL P.L. PLACEMENTS		157	—	157	—	157	—	157	—	157	—
SUPTG. SHUTTLE FLTS	10.1	241	2434	184	1858	186	1879	186	1879	307	3101
MINI-DEPOT COSTS			—		—				129		129
TOTAL			2753		2177		2198		2327		3549

Figure 7.2.3-2 Logistic Program Cost Development Tug/PPS Placements - Program Level C

b. Ground-Based Reusable Tug

The ground-based tug is carried aloft with propellant and a scientific payload by the shuttle. After the payload placement the shuttle retrieves the tug and returns it to earth. On some missions two tugs are required and the expenditure of the tug is required in four missions (see Figure 7.2.3-2).

c. Space-Based Tug Concepts

In the space-based concepts, the shuttle carries a scientific payload and propellant in the logistic tank aloft to the space-based tug. Here, also, two tugs in tandem or expenditure of a tug is occasionally required to perform a mission. Additional shuttle flights are required to bring up the additional tugs.

1. One Tug, No Storage (Minimum Space Shuttle Load)

In Concept 1, only sufficient propellant is carried for each mission, plus enough to maintain the space-based tug between missions. On many missions the full capability of the shuttle is not used. On many other missions second shuttle flights are required to carry the full payload and propellant weight required. This is, therefore, costly in terms of number of shuttle flights.

2. One Tug, Self Storage (Maximum Space Shuttle Load)

The difference between Concepts 1 and 2 is that in Concept 2 the shuttle, as nearly as possible, carries a full 65,000-pound payload on each flight. If there is an excess of propellant, the tug stores it between missions. (The shuttle waits till the tug returns from its flight and then fills it with the excess propellant.) If there is a deficiency of propellant, the tug can use propellant stored from the prior mission. The existence of storage in space results in an economy by reducing the total number of shuttle flights required to conduct the program.

3. Two Tugs, Self Storage

Concept 3 is similar to Concept 2 except that two tugs instead of one are space based. Excess propellant is held in the second tug as a storage vehicle between missions. The tugs alternate in flying the missions. The total storage capacity is increased from one tug to two tugs.

4. One Tug, with Mini-Depot

Here the additional space-based storage is in the form of a mini-depot consisting of the logistic tank from the shuttle cargo bay attached to an equipment module which provides attitude control and rendezvous and docking equipment which enables it to fly as a free space vehicle.

5. One Tug and Mini-Depot with Separate Shuttle Flights for Propellant and Scientific Payload

   Concept 5 is the same as Concept 4 except for the ground rule that scientific payload and propellant require separate shuttle flights. This concept is expensive in that it requires many additional shuttle flights to accomplish the program.

7.2.3.2 Logistics Concept Cost Comparison (Program Level C)

Several important conclusions are drawn from the cost comparison presented in Figure 7.2.3-1. First, the shuttle costs are the logistic program cost drivers. In all the concepts the number of shuttle flights required to conduct the program constitutes the principal cost difference except in the ground-based, non-reusable case. In the ground-based, non-reusable case the cost of expending the FW-4S, Agena or Centaur drives the vehicle costs up over that for the reusable ground-based concept. Among the space-based concepts, the advantage of some form of storage is illustrated by the reduction in shuttle flights and shuttle costs.

The fact that the number of shuttle flights are approximately the same for Concepts 3 (two tugs) and 4 (mini-depot) as for Concept 2 (self storage) indicates that the capacity of storage required is no greater than the capacity of one tug. A slight reduction in shuttle flights for the increased storage capacity of two tugs or mini-depot was actually more than offset by the increased loss of propellant from boiloff and maintenance of two vehicles instead of one. The cost of the mini-depot equipment module simply adds to the program costs without providing any reduction in shuttle or propellant costs. The conclusion drawn is that there is no requirement for a mini-depot.

Concept 5 is costly because of the requirement for separate shuttle flights for propellant and scientific payload. It requires 307 shuttle flights compared with 186 in Concept 2. The propellant logistic tank is 38 feet long leaving 22 feet for payload. The median payload weight in the model is 1000 pounds so that very little offloading of the propellant tank is required to accommodate the payload.

The ground-based reusable concept is the most economical of all. It has been noted, however, that the space-based tug is relatively heavy compared with the ground-based tug. Comparison of the two modes with comparable tugs is made under Sensitivity Studies, Section 8.0. Concept 2 (self storage) was selected among the space-based concepts as the baseline concept for further study in the ISPLS program.

7.2.3.3 Cost Comparison for Program Levels A through E

The conclusions drawn above for Program Level C apply generally to all the program levels in the study. Figure 7.2.3-3 shows the logistic program cost comparison for the logistic concepts employing the ground-based and space-based tugs for Program Levels B through E. The comparative costs among all the concepts are generally the same as for Level C discussed above. Program Levels D and E are more heavily weighted with high energy (geosynchronous placements

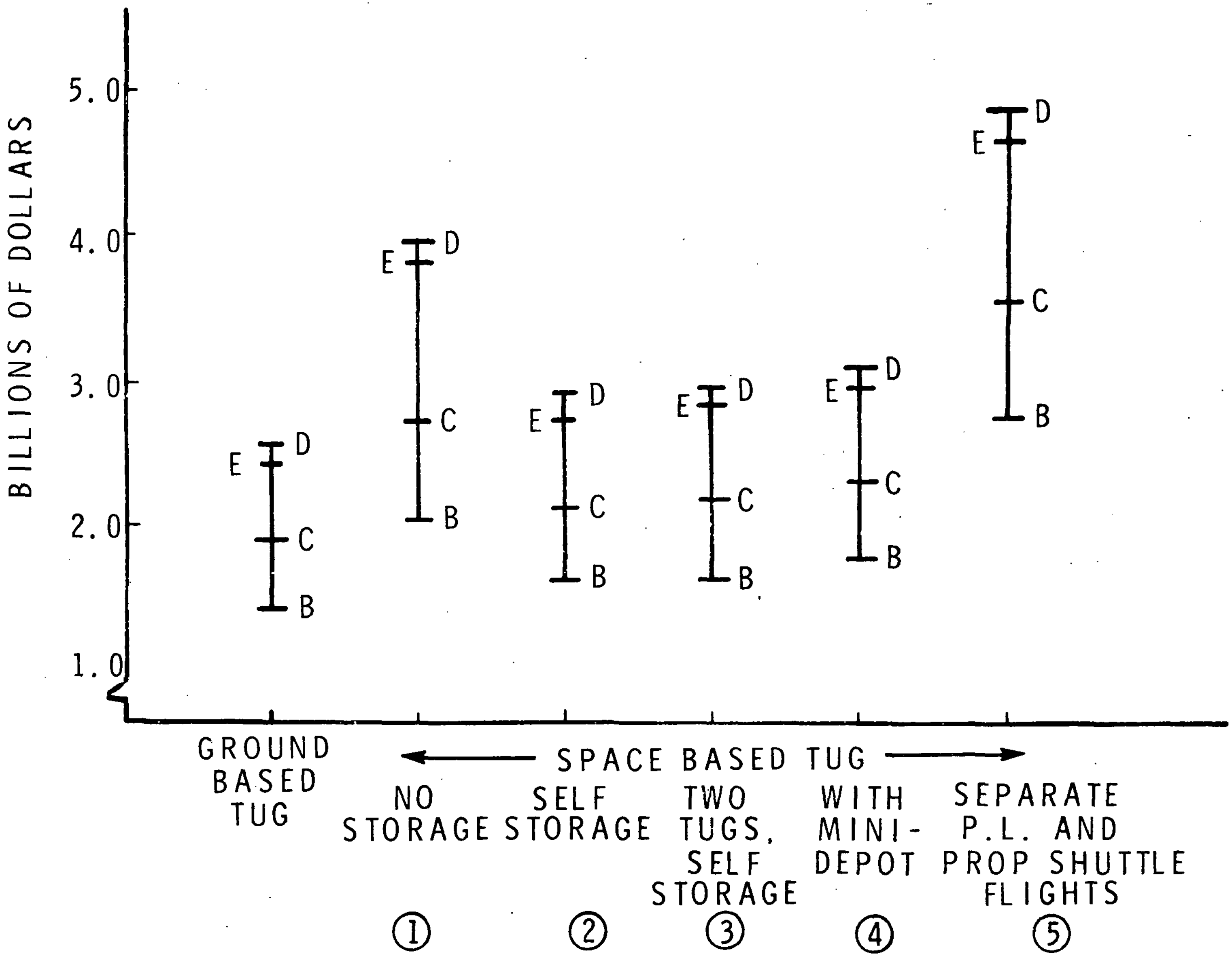


Figure 7.2.3-3 Logistic Program Cost Comparison 1985-1990 by Program Level for Tug Placement Missions

and planetary) missions than B and C, which results in proportionately higher costs for Levels D and E in Concepts 1 (no storage) and 5 (separate shuttle flights). Costs for Program Level E are slightly less than for Level D because E has fewer tug payload placement missions. Five D missions are flown by CIS/RNS in Level E (see CIS/RNS, Section 7.2.4). (The data for Figure 7.2.3-3 are taken from Figure 7.2.5-2 which appears later in the text.)

7.2.3.4 Cost Comparison for Polar Versus Easterly Missions

The relative logistic program costs for the tug/PPS placement missions in the seven operational concepts are shown separately for the polar (90 degrees to 100.7 degrees) and the easterly (0 to 30 degrees) missions in Figures 7.2.3-4 and 7.2.3-5. These are for missions in Program Level C 1985-1990 and are calculated on the same basis as the costs shown in the earlier Figure 7.2.3-1 for the missions of all inclinations combined. Comparison of the data with Figure 7.2.3-1 reveals that the pattern of costs is not significantly different for the easterly missions than for all missions combined. Among the polar missions, however, the ground-based reusable concept is the cheapest concept. The reason for this is that the polar missions are heavily weighted with relatively low altitude missions with light weight payloads (low energy missions). The easterly missions are heavily weighted with geosynchronous placement missions and some planetary missions which require relatively large vehicles and large quantities of propellant. In performing the polar missions with the ground-based, non-reusable vehicles, a larger proportion of the polar missions can be performed with the relatively inexpensive FW-4S derivative solid propellant kick stage instead of the more expensive Agena or Centaur vehicles. This reduces the vehicle portion of the logistic program costs to a low value for the polar missions in the ground-based, non-reusable concept. The easterly missions require a larger proportion of Agenas and Centaurs.

The conclusion to be drawn is that the polar missions should always be flown in a ground-based mode and with the FW-4S or equivalent whenever possible. A space-based tug located at an orbital inclination of 28.5 degrees could serve the 0 to 30-degree missions. The 0 degree geosynchronous missions and all missions up to 28.5 degrees are, of course, supported with easterly launches at 28.5 degrees from Cape Kennedy. The propellant required for the space-based tug to make the plane change from 28.5 to 30 degrees and back for the full load mission would be less than 4000 pounds (7 percent of one shuttle load). Allowance for this has not been made in the calculation but it would not appreciably change the overall cost comparisons. A plane change from 28.5 degrees to 55 degrees and back would require a minimum of 40,000 pounds of propellant for the tug so that the 55-degree missions should also be operated ground-based for the frequency of these missions which occur in the ISPLS model.

The number of payload placement flights in Program Level C 1985-1990 by inclination are as follows:

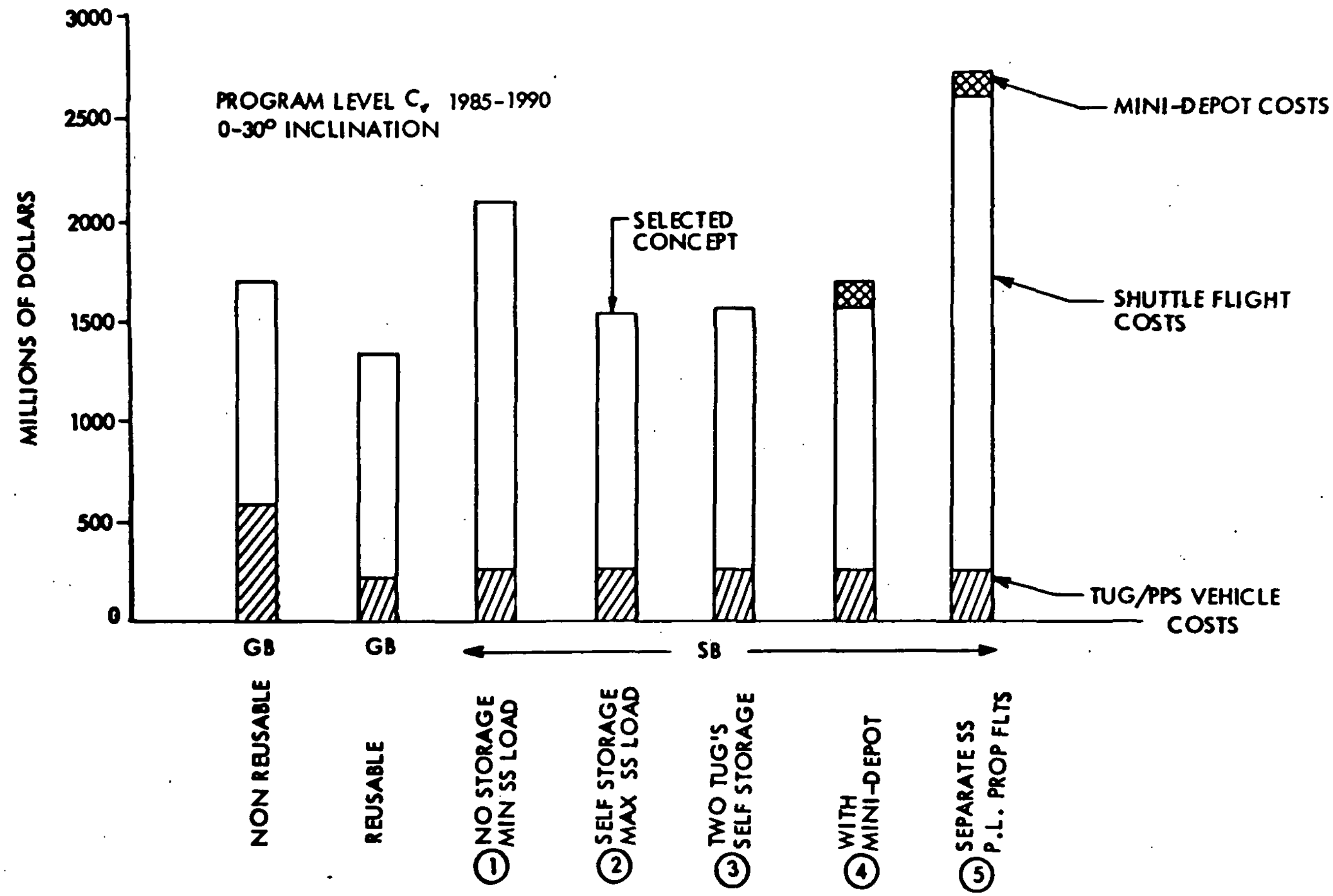


Figure 7.2.3-4 Logistic Program Costs
Easterly Launches
(Payload Placement Missions)

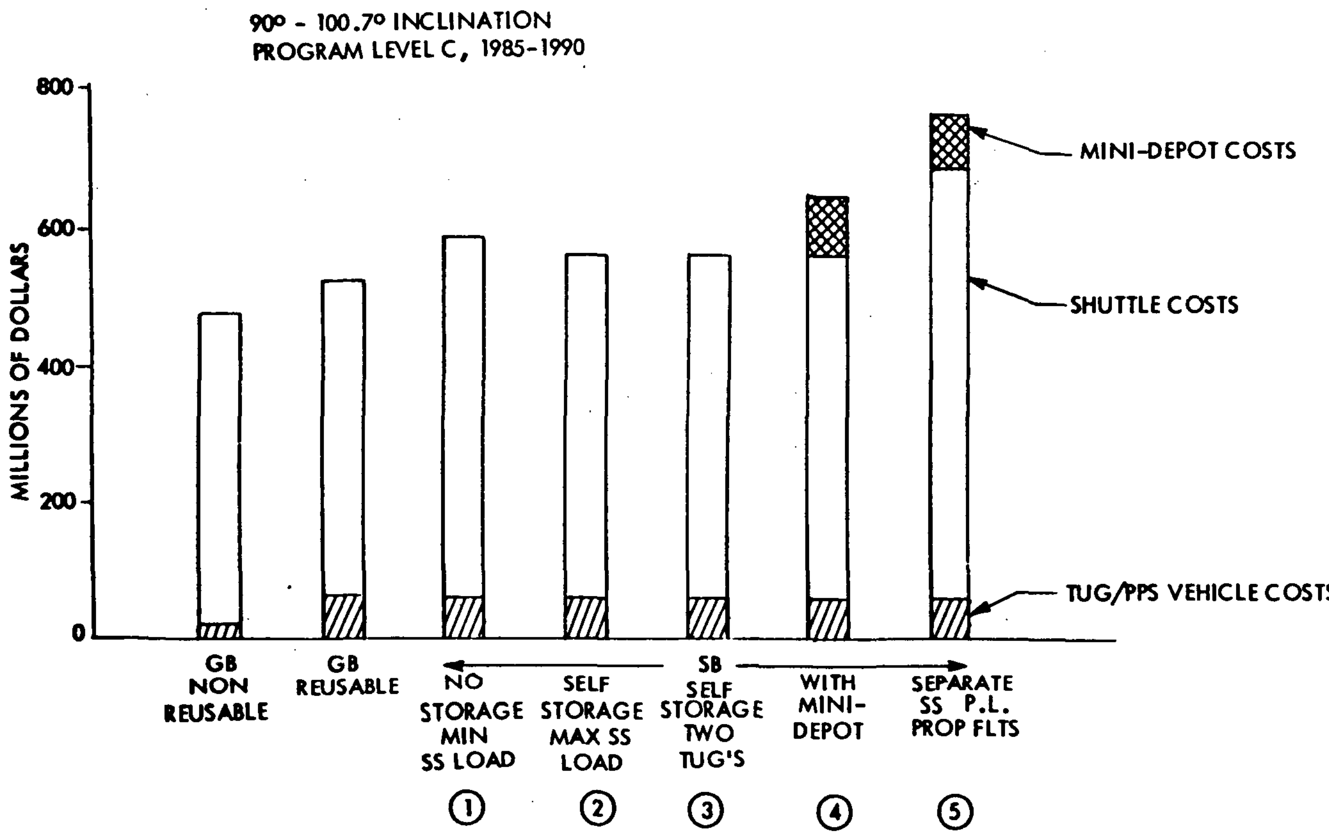


Figure 7.2.3-5 Logistic Program Costs Polar Launches
(Payload Placement Missions)

Orbital Inclination	Number of Payload Placement Flights
0 to 30 degrees	105
55 degrees	6
90 to 100.7 degrees	46
	157

The cost calculations are summarized in Table 7.2.3-1.

Table 7.2.3-1 Polar Versus Easterly Mission Costs
(Non Reusable PPS, Program Level C, 1985-90)

Vehicle Employed	Cost Per Flight $ M	0 - 30°		90-100.7°	
		Flights	Cost $ M	Flights	Cost $ M
FW-4S Der.	0.2	1	0	42	8
Agena	3.2	90	288	4	13
Single Centaur	9.5	7	67	-	-
Two Centaurs	19.0	7	133	-	-
Total Payload Placements		105		46	
Supporting Shuttle Flights	10.0	115	1150	46	460
			$1638		$481

7.2.4 CIS/RNS Missions

The CIS and RNS are space-based vehicles assumed to be operating at a parking orbit altitude of 180 n mi for the ISPLS study. Ten lunar missions spaced over five years are contained in ISPLS Program Levels D and E. For the baseline case, the lunar missions are operated in Mode 2 and the CIS/RNS carries a payload of 320,000 pounds to the moon and 16,800 pounds from the moon. In addition, the CIS/RNS is used to perform five missions which insert payloads on trajectories

toward other planets in Program Level E. The CIS/RNS missions along with the number of supporting shuttle flights required to deliver propellant and payload to the CIS/RNS and the logistic program costs are presented in Figure 7.2.4-1. These costs are compiled in accord with the ISPLS logistic program ground rules and costing procedures and are included in the total program costs in section 7.2.5.

The logistics program cost data include the average cost per flight for the CIS/RNS hardware including its acquisition, initially placing it in space, and its in-space maintenance. Cost of propellant used by the vehicles is reflected in the number of shuttle flights required to deliver propellant to the vehicles. Shuttle flights for delivering payloads to CIS/RNS are included to make the data comparable with the tug/PPS costing procedures wherein the propellant and tug/PPS scientific payloads are carried in the same shuttle flights and are, therefore, costed together. The costs do not include development costs for the CIS/RNS program nor for the acquisition costs or operational costs for the payloads delivered by CIS/RNS.

The data (Figure 7.2.4-1) for the baseline ISPLS cases show that the shuttle costs constitute the major portion of program costs for both the CIS and RNS and that the logistics costs for the CIS vehicle are higher than for the RNS because of its greater propellant use.

Conclusions reached elsewhere in the study indicated that a depot was not required to support either the CIS or the RNS vehicles and that propellant would be delivered to the CIS/RNS vehicles by direct shuttle flights and transferred to the CIS/RNS from the logistics tank carried in the shuttle cargo bay. Mode 1 was the baseline mode of operation for these vehicles in their lunar missions in the early phases of the ISPLS study. At the time the NR CIS study switched to Mode 2 as baseline, Mode 2 was adopted as the ISPLS baseline. Subsequently the CIS study considered the drop tank version of CIS identified as DT1. This occurred so late that it could not be considered in the ISPLS study. Comparisons between Mode 1 and Mode 2 operations are presented below.

7.2.4.1 CIS/RNS Mode 1 and Mode 2 Comparisons

In Mode 1, the space-based CIS or RNS employs its own engines for the required thrust and maneuvers in the lunar mission including return to earth orbit. In Mode 2, the flight plan is the same as Mode 1 on the outbound trip to the moon. On the return trip, the CIS/RNS enters a highly elliptical orbit about the earth with a perigee altitude of 180 n mi and an apogee altitude varying from about 3000 n mi to 15,000 n mi (nominally 5400 n mi) depending on the gross weight of the returning vehicle. The space-based tug is used to retrieve the CIS/RNS from this elliptical orbit. The CIS or RNS is thus required to carry less propellant for the trip. However, costs of the use of the tug and its propellant must be added.

Propellant requirements have been calculated for the CIS and RNS operating in Mode 1 and Mode 2, each with the two different payloads, and are presented in Figure 7.2.4-2. In both the CIS and RNS cases, the data have been based on scaled vehicles which would allow them to carry just the propellant indicated. The data on Mode 1 with 175,000 pounds/15,000 pounds (out/return) payload were

	1979-1984	UNIT COSTS $M	PROGRAM LEVEL D		PROGRAM LEVEL E	
			FLIGHTS	COST $M	FLIGHTS	COST $M
PLANETARY INSERTION FLIGHTS	CIS/RNS PAYLOAD PLACEMENT FLTS	18.8/19.7	—	—	1	19/20
	SHUTTLE FLTS (CIS/RNS PROPELLANT)	10.11/10.13	—	—	10/7	101/70
	SHUTTLE FLTS (CIS/RNS PAYLOAD)	10.0	—	—	3	30/30
	TOTAL					150/120
	CIS/RNS PAYLOAD PLACEMENT FLTS	18.8/19.7	—	—	4	75/80
	SHUTTLE FLTS (CIS/RNS PROPELLANT)	10.11/10.13	—	—	48/30	485/300
	SHUTTLE FLTS (CIS/RNS PAYLOAD)	10.0	—	—	10	100/100
	TOTAL					660/480
LUNAR FLIGHTS	CIS/RNS LUNAR FLIGHTS*	18.8/19.7	10	190/200	10	190/200
	SHUTTLE FLTS (CIS/RNS, TUG PROPELLANT)	10.11/10.13	200/146	2020/1480	200/146	2020/1480
	SHUTTLE FLTS (CIS/RNS PAYLOAD)	10.0	60	600/600	60	600/600
	TOTAL			2810/2280		2810/2280
	PROGRAM TOTAL			2810/2280		3620/2880

*MODE 2 OPERATION

Figure 7.2.4-1 CIS/RNS Propellant Logistic Program Cost Summary

	CIS(1)				RNS(2)			
	MODE 1		MODE 2		MODE 1		MODE 2	
PAYLOAD, OUT/RETURN, K#	175/15	320/16.8	175/15	320/16.8	175/15	320/16.8	175/15	320/16.8
PROPELLANT(3): CIS/RNS #	990,000	1,345,000	676,000	963,000	300,000	420,300	241,000	354,000
TUG #			79,000	79,000			79,000	79,000
TOTAL #	990,000	1,345,000	755,000	1,042,000	300,000	420,300	320,000	433,000
TEN FLIGHT PROGRAM (5 YRS)								
SHUTTLE FLIGHTS: PROPELLANT	19	26	15	20	11	15	11	15
CARGO	4	6	4	6	4	6	4	6
COSTS:	$M	$M	$M	$M	$M	$M	$M	$M
CIS/RNS VEHICLE COSTS	190	190	190	190	200	200	200	200
SHUTTLE FLIGHT, PROPELLANT	1,920	2,580	1,500	2,020	1,050	1,440	1,110	1,480
SHUTTLE FLIGHT, CARGO	400	600	400	600	400	600	200	600
TOTAL LOGISTIC COSTS	2,510	3,370	2,090	2,810	1,650	2,240	1,710	2,280
FIVE FLIGHT PROGRAM (5 YRS)								
TOTAL LOGISTIC COSTS	1,310	1,740	1,100	1,460	880	1,170	910	1,190
TWENTY FLIGHT PROGRAM (5 YRS)								
TOTAL LOGISTIC COSTS	4,920	6,640	4,070	5,520	3,220	4,390	3,340	4,470

(1) CIS BASED ON PARAMETRIC CIS, CHART 287, PAGE 89, DEC. 15, 1971, PRESENTATION, NR CIS DESIGN AND SYSTEM ANALYSIS STUDY
(2) RNS DATA BASED ON NR NUCLEAR FLIGHT DEFINITION STUDY, APRIL 1971 FINAL REPORT
(3) INCLUDES OTHER CONSUMABLES; CIS/RNS SCALED FOR LARGER/SMALLER PAYLOADS

Figure 7.2.4-2 CIS/RNS Mode 1, Mode 2 Logistic Program Cost Data

the baseline cases used in the early phases of the ISPLS study. The Mode 2 cases and 320,000 pounds/16,800 pounds are used as baseline cases in the final phases of the ISPLS study. They are based on the same NR contract studies referred to in Section 7.2.2.

The CIS data for Mode 1 and 2 with the 320,000 pounds/16,800 pounds payload are also reflected in the data from the NR CIS study being conducted concurrently with the ISPLS study. (See "Design and Analysis of a Chemical Interorbital Shuttle", Contract NAS8-27070, Briefing on Phase II Results, December 15, 1971, SD 71-586, page 89.) Data for the other cases have been calculated for this comparison on a consistent basis.

Total logistics program costs have been developed in accordance with the procedures used elsewhere in the ISPLS study for 5, 10, and 20 flight programs. The data indicate for the RNS that for an equal payload per flight, Mode 2 is slightly more expensive than Mode 1. This is because RNS is a relatively light weight vehicle compared with the CIS and it has a high specific impulse defined as 775 seconds versus 454 seconds for the CIS. As a consequence of its high I_{sp} and relatively light weight, it is not economical for a tug with specific impulse of 463 seconds to retrieve it on its return trip to earth. Nevertheless, as is also shown in subsequent Figures 7.2.4-3 and 7.2.4-4, it is more economical to fly given payloads to the moon with RNS than CIS in Mode 2 as well as in Mode 1. The allowance in Figure 7.2.4-2 for number of shuttle flights required to carry CIS/RNS cargo to the CIS/RNS vehicles has been developed consistent with the allowances made in the concurrent CIS study.

The logistic program cost data from Figure 7.2.4-2 are extended and plotted as a function of the number (frequency) of CIS/RNS lunar flights in a five-year program in Figure 7.2.4-3. The figure indicates that, although RNS Mode 2 flights are more expensive than RNS Mode 1 flights, RNS is cheaper than CIS for an equal payload in both Mode 1 and Mode 2. The four circled points in the chart reflect the cases presented in Figure 7.2.4-4.

Figure 7.2.4-4 presents comparative logistic program costs for CIS and RNS on the assumption that each of the vehicles is to carry the same total payload of 1,750,000 pounds to the moon in a five-year program.

The CIS Mode 1 case employing 990,000 pounds of propellant and carrying 175,000 pounds of payload and the CIS Mode 2 case employing 1,041,640 pounds of propellant (including tug use) are the baseline Mode 1 and Mode 2 cases used in the ISPLS study and taken from the concurrent CIS study. In Mode 1 the total payload of 1,750,000 pounds requires 10 flights at 175,000 pounds per flight. In Mode 2 six flights are required at 320,000 pounds per flight employing the same CIS vehicle. For the RNS, 10 flights are required in Mode 1. The same RNS vehicle can carry 250,000 pounds in Mode 2 and a total of 7 flights are required.

The overall costs are calculated for the four cases and as noted above they are also spotted by circles on the preceding Figure 7.2.4-3. The data show the advantage of carrying larger payloads on each flight and reducing the number of flights in order to maximize the total payload carried to the moon over a period of time.

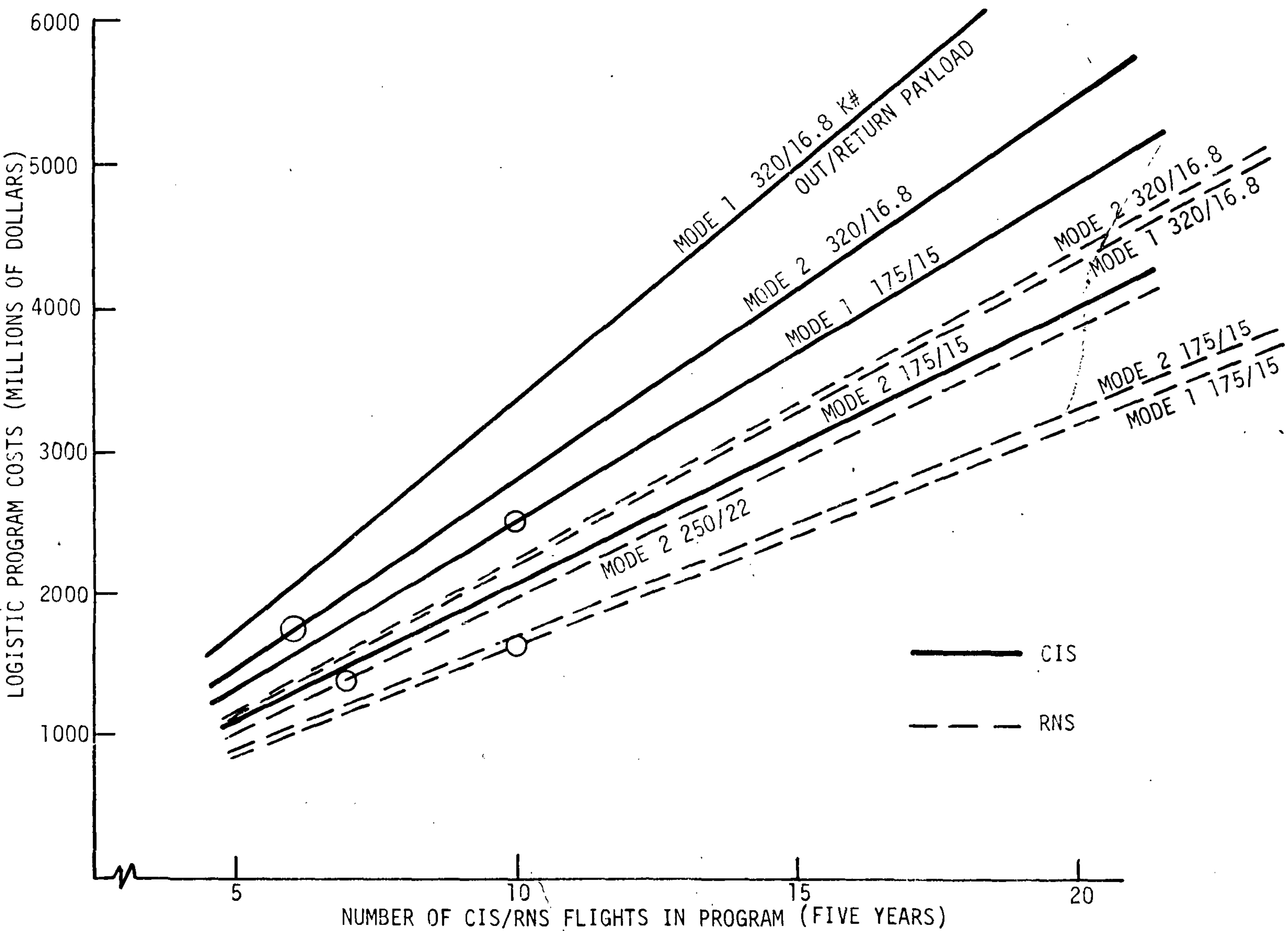


Figure 7.2.4-3 Logistic Program Costs Versus CIS/RNS Mode 1, Mode 2 Flights

		CIS				RNS			
		MODE 1		MODE 2		MODE 1		MODE 2	
TOTAL PROGRAM PAYLOAD	OUT	1,750,000#		1,750,000#		1,750,000#		1,750,000#	
	RETURN	150,000		150,000		150,000		150,000	
PAYLOAD PER FLIGHT		175/15		320/16.8		175/15		250/22	
CIS/RNS PROPELLANT PER FLIGHT		990,000#		1,041,640#*		300,000#		379,000#*	
UNIT COST $M		FLTS	COST	FLTS	COST	FLTS	COST	FLTS	COST
CIS/RNS FLIGHTS	18.8/19.7	10	$188M	6	$113M	10	$197M	7	$138M
SHUTTLE FLIGHTS: **									
VEHICLE PROP.	10.11/10.13	190	$1,922	114	$1,152	100	$1,013	70	710
PAYLOAD	10.0	40	400	40	400	40	400	40	400
TUG PROPELLANT	10.11	--	--	9	91	--	--	10	
		230	2,322	163	1,643	140	1,413	120	1,111
TUG: FLIGHTS	1.3	--	--	6	8	--	--	7	9
TOTAL LOGISTICS: PROGRAM COSTS	$M		2,510		1,764		$1,610		$1,258

*INCLUDES 78,640# FOR TUG

** SHUTTLE FLIGHT COSTS INCLUDE AN ALLOWANCE FOR THE LOGISTIC TANK

Figure 7.2.4-4 Mode 1, Mode 2, CIS/RNS Cost Comparison for Equal Payloads (5 Year ISPLS Program, Level E)

An overall conclusion of the analysis is that RNS does not derive an economy in "propellant logistic program costs" from Mode 2 operation as opposed to Mode 1, as does the CIS. The propellant logistic costs for the RNS, however, are less than for CIS for equal payloads in either Mode 1 or Mode 2.

Figure 7.2.4-5 has been prepared to present parametrically the program costs of the two modes for CIS/RNS as a function of the propellant used per flight and the number of flights in the program. The cargo that the CIS/RNS can carry also increases as the propellant consumption increases. The logistic program costs include shuttle flights to carry the CIS/RNS cargo as well as propellant. Inclusion of CIS/RNS cargo delivery has been considered necessary in the ISPLS costing procedure for consistency with the tug costing procedure.

Figure 7.2.4-6 shows a breakdown of the costs for the Mode 2 (20 flights) CIS case, which is one of the curves on Figure 7.2.4-5. It illustrates the proportion of the total costs which are accounted for by propellant versus cargo requirements. It is interesting to note that for an increase of cargo from 120,000 pounds to 320,000 pounds (2.7 to 1), the propellant used increases from about 685,000 pounds to 1,042,000 pounds (1.5 to 1), which illustrates the greater economy per pound of payload delivered by carrying larger payloads on each flight.

7.2.5 Total Program Costs

The total logistic costs for the program categories compiled in accordance with the ISPLS study ground rules on the availability of vehicles are presented in Figure 7.2.5-1. The ground rules and cases were presented earlier in the study in Section 3.0.

The study ground rules provided that Program Level A should employ only the nonreusable PPS (FW-4S, Agena or Centaur), and that the tug, space-based or ground-based, would not be available until 1985, except in Program Levels D and E, where comparison of tug with the nonreusable vehicles would be made in the earlier years. Wherever the tug is employed, comparison would be made between the space-based and ground-based versions. These ground rules resulted in the combination of cases shown in the left hand columns of Figure 7.2.5-1. CIS/RNS missions are included in Levels D and E.

The comparisons are made of the total program costs with the space-based portions operating in the five logistic operational concepts for payload placement missions within the various program levels.

The data in Figure 7.2.5-2 shows the logistic program costs separately for the years 1979-84 and 1985-90 for all program levels and for the two ground-based and five space-based operational concepts. In addition the logistic costs for the CIS/RNS missions included in Program Levels D and E are shown at the bottom of the table. The data in Figure 7.2.5-1 are made up by addition of the costs for the appropriate operational concepts for the period of years and in the program levels shown in Figure 7.2.5-2. The method of development of these costs is described in earlier sections and an example is presented for PPS/tug missions for Program Level C in Figure 7.2.3-2. CIS/RNS data are developed in the preceding section.

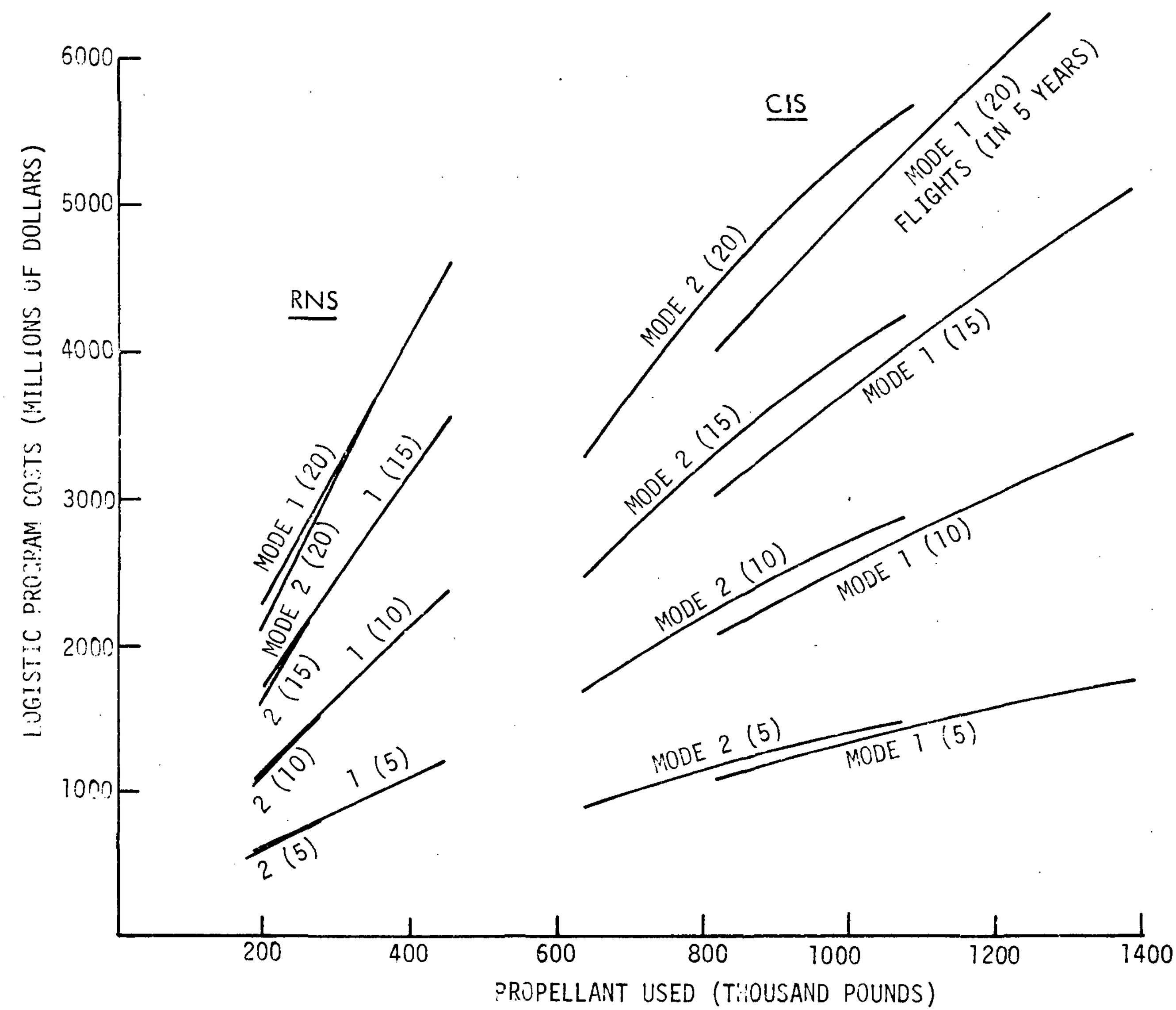


Figure 7.2.4-5 Logistic Program Costs Versus Propellant Requirements CIS/RNS, Mode 1, Mode 2

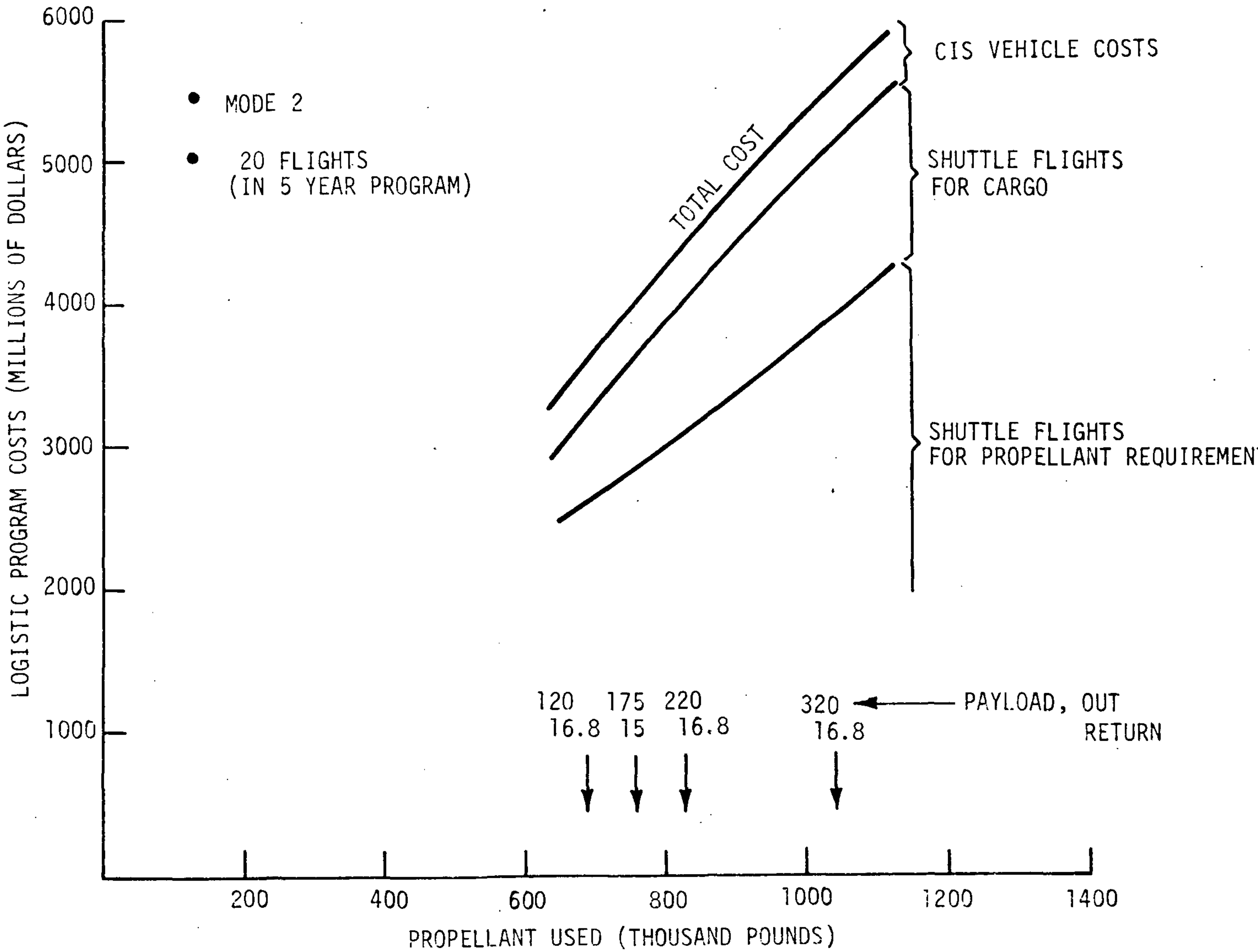


Figure 7.2.4-6 Logistic Program Cost Breakdown Versus Propellant Requirement for CIS

PROGRAM LEVEL	PAYLOAD PROPULSIVE SYSTEM		TOTAL LOGISTIC PROGRAM COSTS 1979-1990					
			GROUND BASED ONLY	WITH SPACE BASED PORTIONS, BY CONCEPT				
	1979-1984	1985-1990		NO STORAGE MIN SS LOAD	SELF STORAGE MAX SS LOAD	TWO TUGS SELF STORAGE	WITH MINI DEPOT	SEPARATE SS PL PROP FLTS
			$M	1 $M	2 $M	3 $M	4 $M	5 $M
A_1	NON-REUSABLE	NON-REUSABLE	2510					
B_1	NON-REUSABLE	GB TUG	3189					
B_2 -	NON-REUSABLE	SB TUG		3797	3383	3393	3522	4461
C_1	NON-REUSABLE	GB TUG	4068					
C_2 -	NON-REUSABLE	SB TUG		4878	4302	4323	4452	5674
D_1 (1)	NON-REUSABLE	GB TUG	8443/7913					
D_2 -	NON-REUSABLE	SB TUG		9812/9282	8771/8241	8822/8292	8951/8421	10698/10168
D_3	GB TUG	GB TUG	8053/7523					
D_4	SB TUG	SB TUG		10808/10278	8646/8116	8697/8167	8863/8333	12609/12079
E_1 (1)	NON-REUSABLE	GB TUG	9139/8399					
E_2	NON-REUSABLE	SB TUG		10475/9735	9455/8715	9495/8755	9624/8884	11321/10581
E_3	GB TUG	GB TUG	3749/8009					
E_4	SB TUG	SB TUG		11471/10731	9330/8590	9370/8630	9536/8796	13232/12492

(1) LEVELS D & E WITH CIS/RNS MISSIONS

Figure 7.2.5-1 Total Logistic Program Costs by Space Based Concepts 1979-1990

	REUSABLE TUG AVAILABLE IN 1984										REUSABLE TUG AVAILABLE IN 1979			
PROGRAM LEVEL	A		B		C		D		E		D		E	
YEARS	79-84	85-90	79-84	85-90	79-84	85-90	79-84	85-90	79-84	85-90	79-84	85-90	79-84	85-90
TUG/PPS PAYLOAD PLACEMENTS	83	85	123	117	156	157	218	211	218	206	218	211	218	206
CIS/RNS MISSIONS								10	1	14		10	1	14
PERIOD OF USE OF NON-REUSABLE PPS (FW-4S, AGENA, CENTAUR)														
PERIOD OF USE OF GB/SB REUSABLE TUG														
PERIOD OF USE OF CIS/RNS														
LOGISTIC PROGRAM COSTS:	$M		$M		$M		$M		$M		$M		$M	
NON-REUSABLE PPS	1206	1304	1714		2125		3051		3051					
GB REUSABLE TUG				1475		1943		2582		2468	2661	2582	2661	2468
SPACE BASED TUG:														
CONCEPT														
① ONE TUG, NO STORAGE				2083		2753		3951		3804	4047	3951	4047	3804
② ONE TUG, SELF STORAGE				1669		2177		2910		2784	2926	2910	2926	2784
③ TWO TUGS, SELF STORAGE				1679		2198		2961		2824	2926	2961	2926	2824
④ ONE TUG WITH MINI DEPOT (VEHICLE COSTS)				1679		2198		2961		2824	2926	2961	2926	2824
(DEPOT COSTS)				129		129		129		129	83	83	83	83
TOTAL				1808		2327		3090		2953	3009	3044	3009	2907
⑤ ONE TUG WITH SEPARATE PAYLOAD & PROPELLANT SHUTTLE FLIGHTS VEHICLE COSTS				2618		3420		4708		4521	4925	4708	4925	4521
DEPOT COSTS				129		129		129		129	83	83	83	83
TOTAL				2747		3549		4837		4650	5008	4791	5008	4604
CIS/RNS MISSION COSTS								2810/ 2280	150/120	3470/ 2760		2810/ 2280	150/120	3470/ 2760

Figure 7.2.5-2 Total Logistic Program Costs by Program Level and Payload Delivery Vehicle Employed

8.0 SENSITIVITY ANALYSIS

The sensitivity study results presented in this part of the report are concerned primarily with the sensitivity of the propellant logistics operational concepts for the scientific payload placement missions to variations in tug mass fraction, shuttle performance capability, and potential growth in the scientific payloads.

The operational concepts are the same as those for which the cost analysis was conducted in the preceding section which led to the selection of Concept 2, employing one tug in a self storage mode. The sensitivity analysis shows that a higher mass fraction tug than the baseline space-based tug, used in the study, could bring the logistic cost of space-based operation down to a level equal or just slightly less than the comparable logistic costs for ground-based operation for the "easterly" inclination missions.

With respect to the capability of the space shuttle, the analysis indicates that the logistic program costs are very sensitive to shuttle payload capability and payload bay length. The number of shuttle flights required to conduct the program increases nearly 50 percent for a shuttle with a 45,000-pound payload capability or for a shuttle with a 45-foot payload bay length. The logistic program costs are less sensitive to growth in payload weight and size.

8.1 VARIATIONS IN TUG MASS FRACTION

The three tugs identified on Figure 8.1-1 have been used in the subsequent analysis to evaluate the effect of mass fraction on logistics program performance and cost. For this purpose, the three tugs have to be compared as if they were each operable in either a space-based or a ground-based mode. Neither the point design tug nor the ground-based tug are, in fact, capable of space-based operation because they do not have provisions for transfer of propellant in space. It is also considered that they would require augmented computing capacity for additional remote control and monitoring and additional redundancy for space-based operation. The addition of these provisions would drive the mass fraction of each of these two tugs part way toward the space-based tug figure. Mass fraction has been defined here as in the point design tug contract as the full thrust usable propellant divided by the gross weight. The three tugs have approximately the same overall performance capabilities so that their comparison, made as if they could all be used in a space-based mode or in a ground-based mode, gives an indication of the effect of mass fraction alone on the logistics program operation.

The space-based tug employed in the ISPLS study was defined under NASA Contract NAS9-10925 in accordance with requirements which resulted in a relatively heavy vehicle. It is completely man rated with provisions for attachment of a crew module and is convertible to a moon lander. It has quadruple redundancy in its electronic systems, has four engines, and a separable intelligence module.

The version of the ground-based tug used in the ISPLS study was taken from an early version of the Orbit-to-Orbit Shuttle (OOS) defined under Air Force Contract which was in process at the time the definition for the ISPLS was

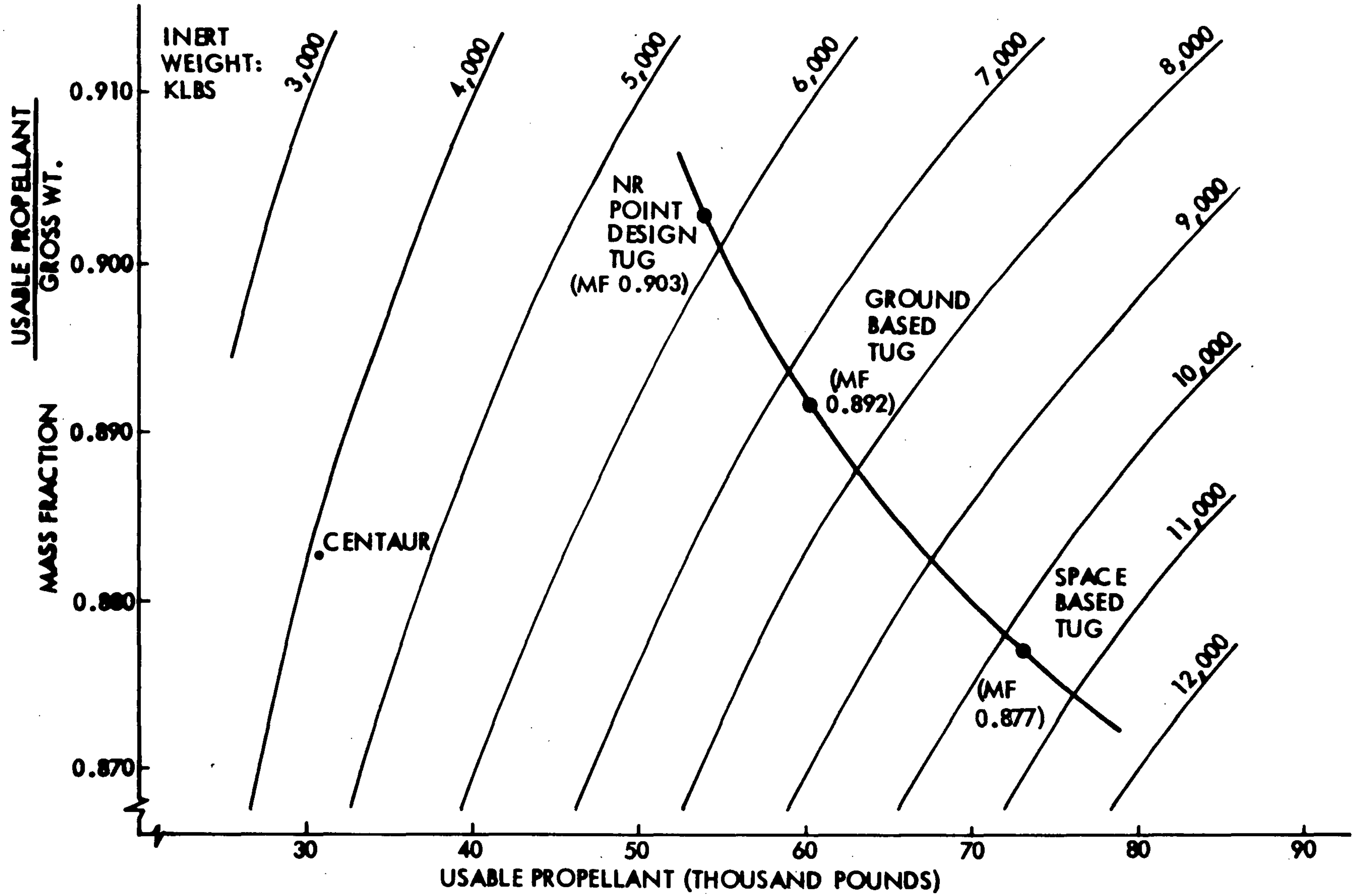


Figure 8.1-1 Tug/PPS Mass Fraction, Propellant Relationships

made. (NR/AF Contract F04701-71-E-0171.) The ground-based tug has two engines, backup functional redundancy, and integral electronics. The final design of the OOS at the completion of the OOS contract had a slightly lower mass fraction than the early version which was used in the ISPLS study.

The primary objective of the point design tug study was to consider advanced technology and other measures to define a higher mass fraction ground-based tug. It employs 1976 technology compared with 1972/73 technology for the ground-based tug and the space-based tug. It makes extensive use of composite materials, has a single engine, and only fail safe redundancy. It is believed that a space-based tug could be built, employing the point design tug technology and some relaxation of earlier ground rules, which would have a higher mass fraction than the space-based tug indicated here. The point design tug design concept was developed by NR under SA2190 to Contract NAS7-200. Comparative mass fraction data are shown in Table 8.1-1 for the three tugs.

A comparison was made of the several logistic operational concepts employing the tugs of the three mass fractions described above with each operating in all the concepts and is presented in Figure 8.1-2. The data in the figure and concepts are comparable to those described in the earlier Figures 7.2.3-1 and 7.2.3-4 with the exception that here all three tugs are used in each concept and the number of shuttle flights for the conduct of the total program in each case is the ordinate instead of program costs. Examination of Figure 7.2.3-4 indicates that shuttle flights constitute the major cost difference and that differences in hardware costs are a relatively small part of the total logistic program costs. Figure 8.1-2 relates to easterly 0-30° missions only so that it covers the same missions as Figure 7.2.3-4. Concept 5, requiring separate shuttle payload and propellant flights, is omitted and Concepts 3 and 4 are shown as one because they require equal numbers of shuttle flights.

Figure 8.1-2 indicates a significant advantage for space-based versus ground-based operation for the low mass fraction, relatively heavy, space-based tug. There is a saving of nearly 50% in the number of shuttle flights by operation in Concept 2 as opposed to a ground-based concept with the heavy tug. The figure also indicates a significant advantage for space-based storage as opposed to no storage.

For the higher mass fraction tugs, there is little difference between the concepts except for a slight advantage in the space-based concept with storage. In other words, with a higher mass fraction tug, space-based operation with storage is cost effective and actually requires slightly fewer shuttle flights than ground-based operation.

For this portion of the program (easterly missions, 1985-1990, Program Level (C), there are 105 scientific payload placements to be made. In each case there must thus be at least 105 shuttle flights to carry the 105 scientific payloads in this program. The higher mass fraction tugs are efficient enough so that propellant requirements are not a controlling factor, as they are in the case of the low mass fraction tug (0.877). The excess over 105 shuttle flights is determined by the payload length or the need to use two tugs to handle a few missions with the higher mass fraction tug.

Table 8.1-1 Comparative Tug Mass Data for Tugs Used in ISPLS Sensitivity Study

	Space Based Tug	Ground Based Tug	Point Design Tug
Inert Weight (lbs)	10,200	7,270	5,800
Usable Propellant (lbs) (Full Thrust)	73,200	60,210	54,030
Gross Weight (lbs)	83,400	67,480	59,830
Mass Fraction (1)	.877	.892	.903
Length Used in ISPLS Analysis (2) (ft)	47	39	38
Actual Length of Vehicle (ft)	44	36	35

(1) Usable (full thrust) propellant divided by gross weight.

(2) Length occupied in Shuttle cargo bay. Includes allowance for swing out mechanism.

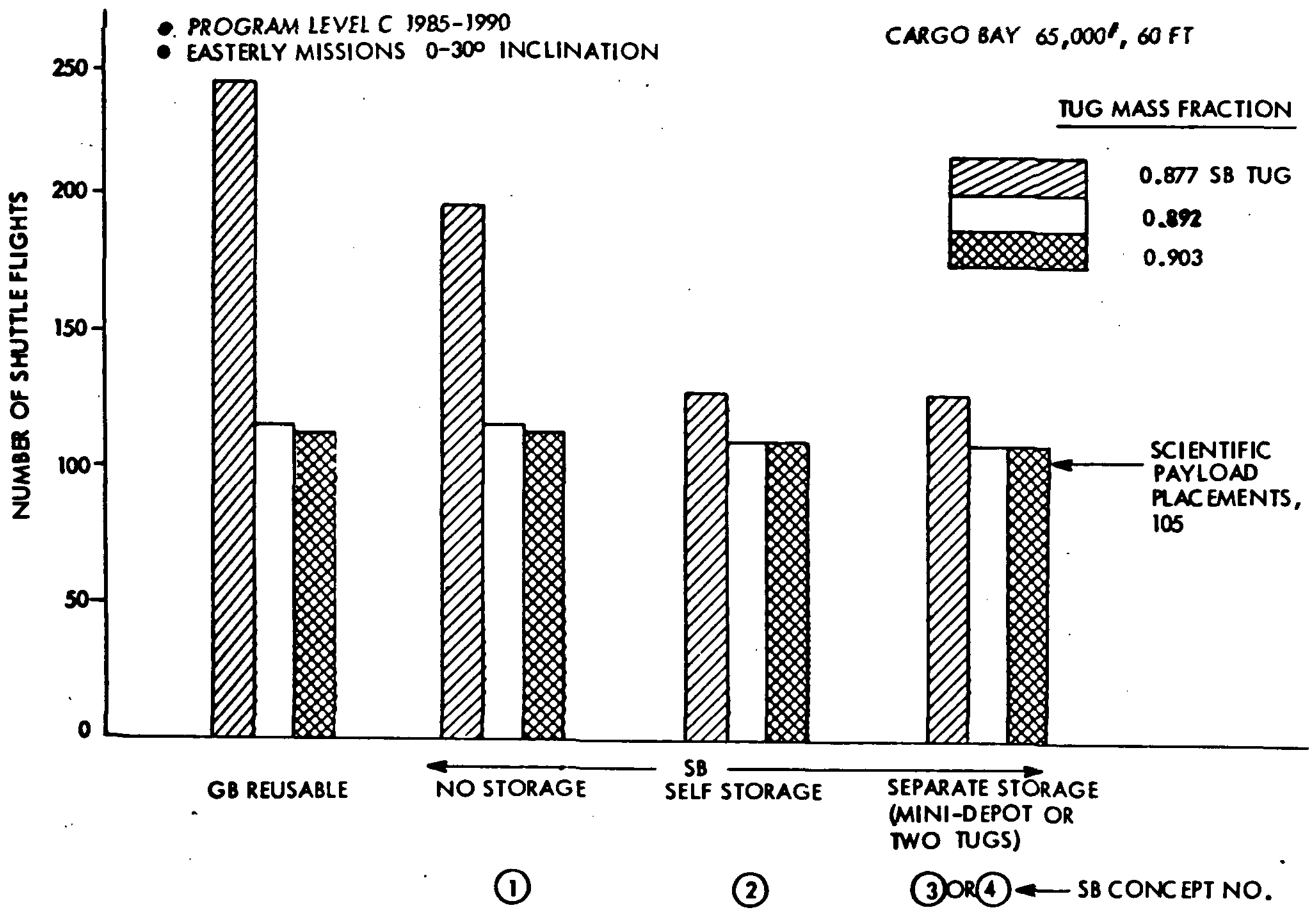


Figure 8.1-2 Concept Sensitivities to Tug Mass Fraction with Baseline Shuttle

The overall conclusion drawn is that the higher cost of space-based operation with self storage over ground-based operation shown earlier in the study, Figures 7.2.3-1 and 7.2.3-4, was due to the higher weight of the space-based tug. For equal tugs, the difference disappears.

8.2 VARIATION IN SHUTTLE CAPABILITY

The above comparisons are based on a baseline shuttle with a capability to place a 65,000 lb payload in orbit. Figure 8.2-1 presents the same data as in Figure 8.1-2 except that it is based on a shuttle with a capability of placing only 45,000 lbs of payload in orbit. Because of the limited capability of the shuttle, the sensitivity of the system to tug mass fraction becomes very great. It may also be noted that space-based operation with propellant storage, Concepts 2 and 4, are much more efficient than ground-based operation. With a limited capability shuttle, propellant requirements become a controlling factor in the number of shuttle flights for all three tug mass fractions.

Sensitivities in terms of the number of shuttle flights are shown in Figure 8.2-2 for variations in the shuttle payload weight capability and shuttle cargo bay length and also for an increase in the weight and length of the scientific payloads which are contained in the scientific payload placement mission models (Program Level C, 1985-1990, 0-30°). The comparison is made for operation of the baseline shuttle and space-based tug operating in space-based concept No. 2.

Care must be taken in making comparisons between the curves in Figure 8.2-2 since their relative position on the chart can change by stretching or shortening the scales used at the bottom of the chart. Nevertheless, if a 45,000 lb capability shuttle with a 45 foot bay length is equated to a 50 percent growth in scientific payloads, the system is much more sensitive to shuttle capability than to payload growth. The relative insensitivity of the system to scientific payload weight changes is probably the most significant conclusion of the figure. The mean scientific payload weight is less than 2000 pounds and the median weight is 1000 pounds in the program model. Because all the missions are payload placement missions (one way outbound payload), an increment of less than 2 pounds of propellant is added for each pound of additional payload, on virtually all missions and much less on some. It may be noted that the figure indicates that the payloads could increase in length by 3 to 4 feet or the shuttle bay could be shortened by 3 to 4 feet without any increase in shuttle flights. It should be noted, however, that the data are based on a logistic tank length of 38 feet. When the more detailed design of the logistic tank was completed late in the study, provisions for a swing-out mechanism increased its overall length to about 41 feet.

Figure 8.2-3 shows the sensitivity of space-based Concept 2 to variations in shuttle payload capability for the three tugs with different mass fractions discussed earlier. The top curve is the same as shown in Figure 8.2-2. Conduct of this portion of the program in Concept 2 (space-based self storage) requires 128 shuttle flights employing the baseline shuttle with 65,000 lbs payload capability and the heavy space tug. This increases to over 180 shuttle flights if the shuttle payload capability were reduced to 45,000 lbs. If the light weight tugs are used with the baseline shuttle, the number of shuttle

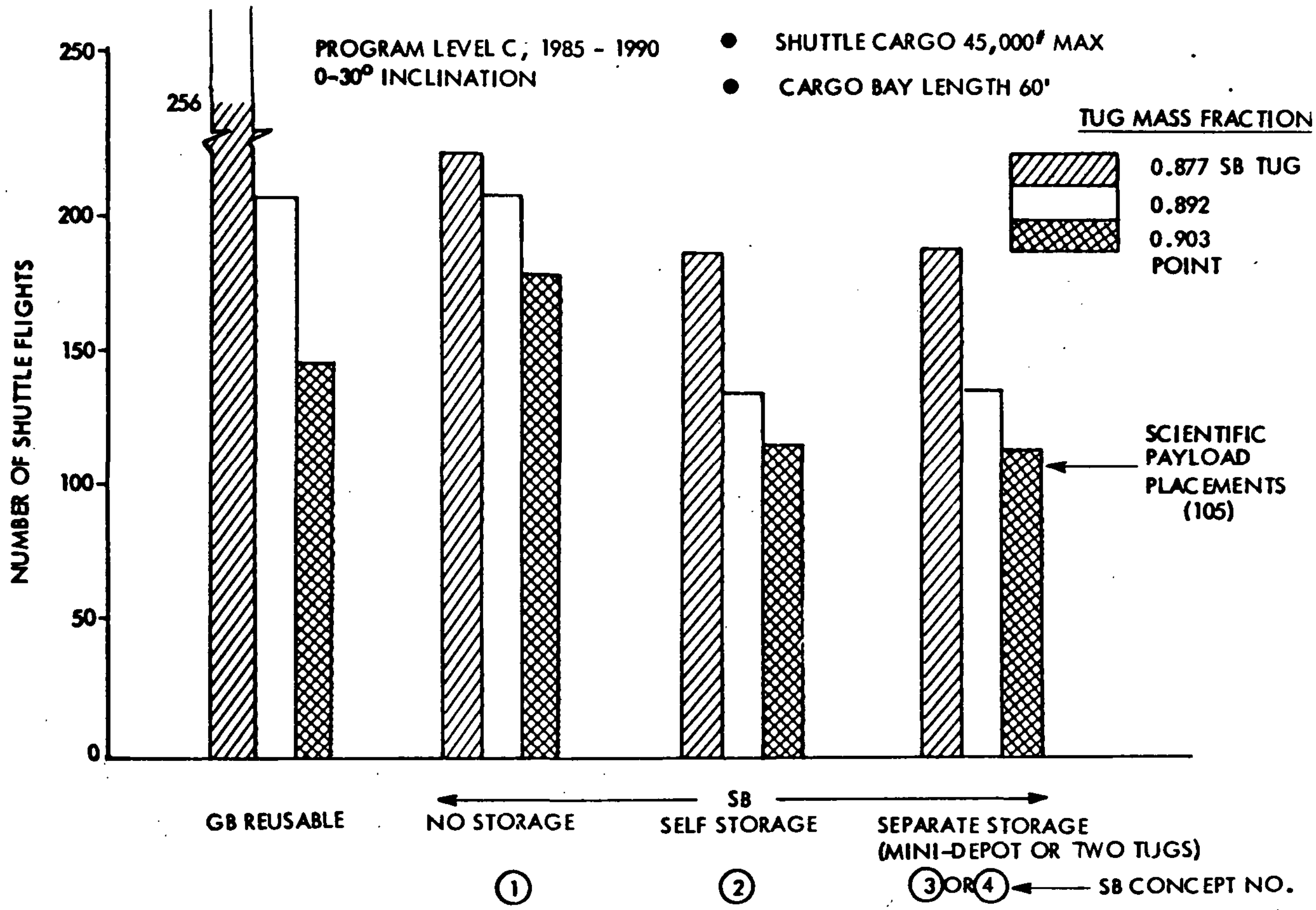


Figure 8.2-1 Concept Sensitivities to Tug Mass Fraction
with 45,000 Lb. Shuttle

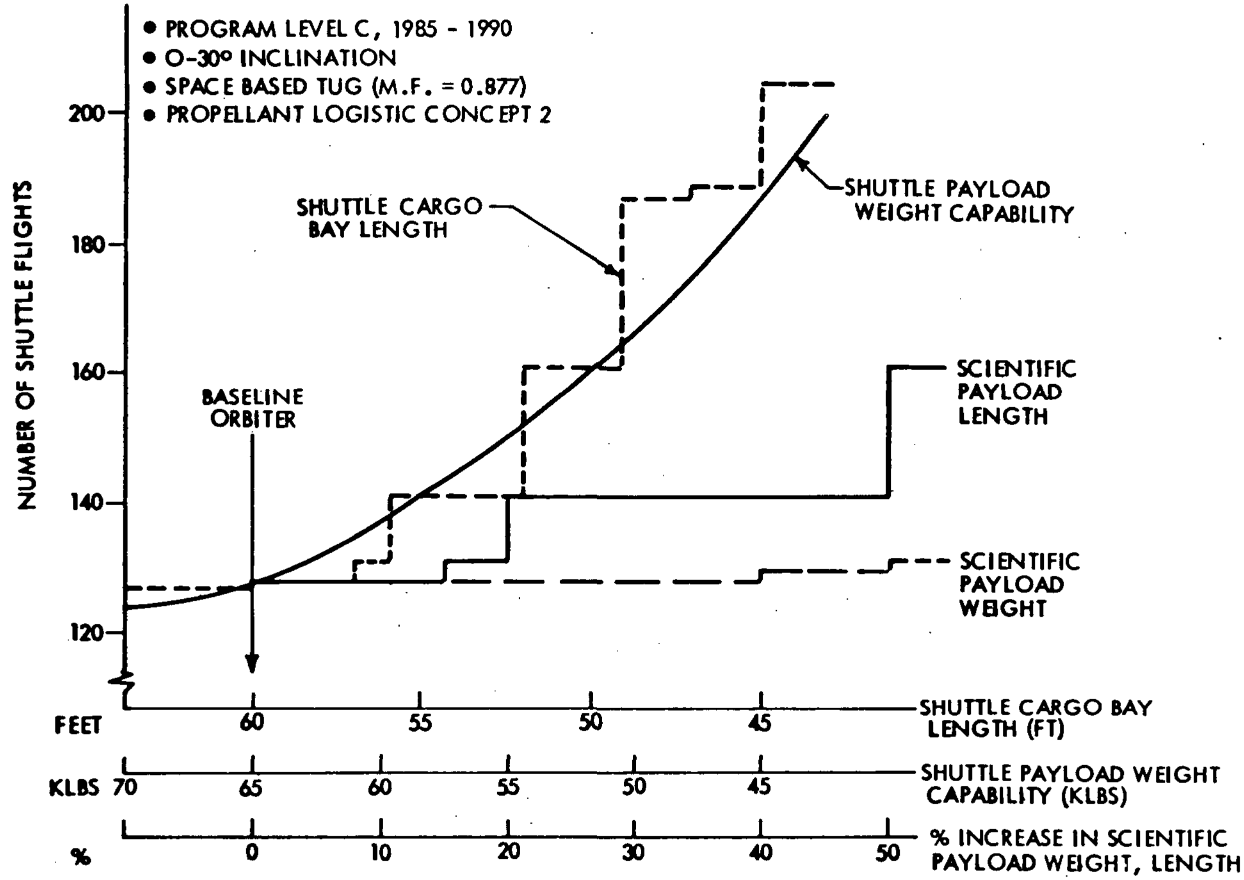


Figure 8.2-2 Shuttle Orbiter Flight Sensitivities

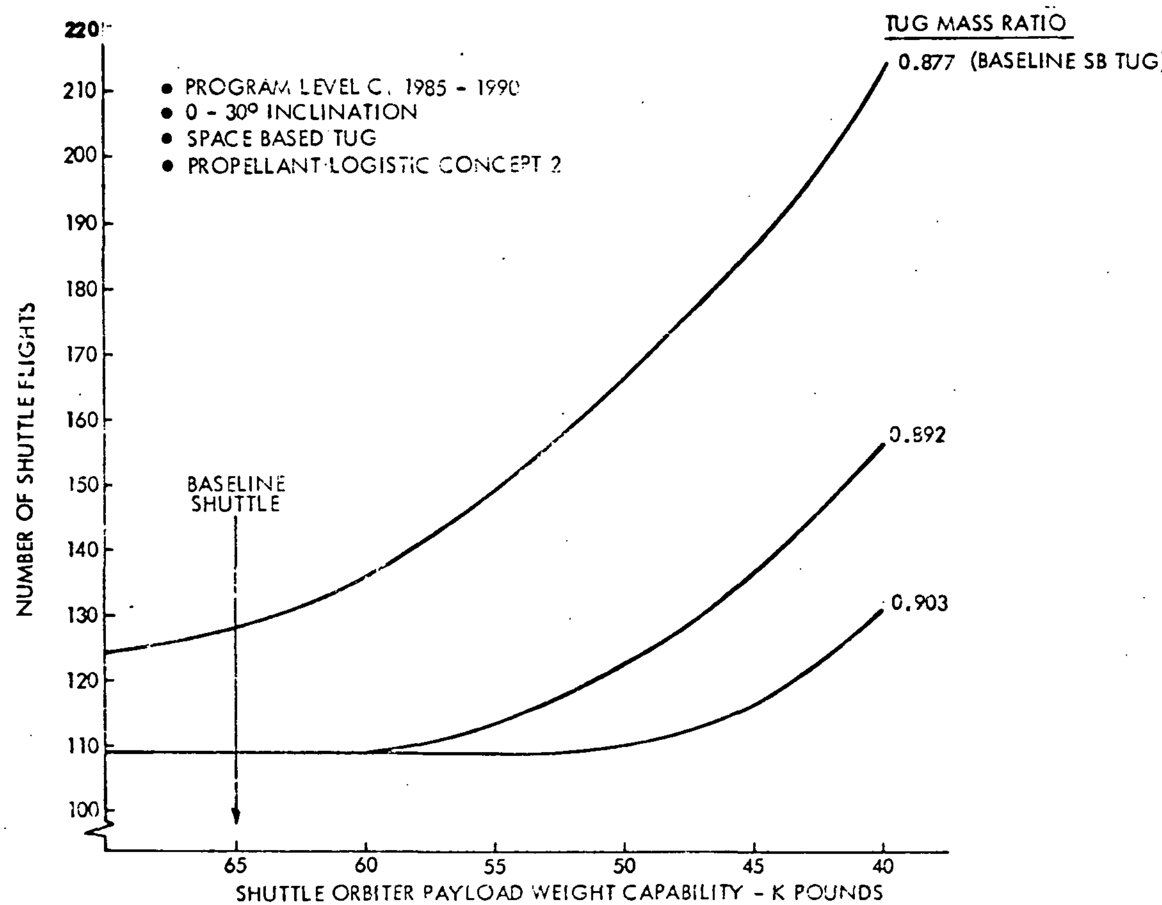


Figure 8.2-3 Sensitivity to Shuttle Payload Capability and Tug Mass Ratio

flights is reduced to 109 flights. This number remains relatively insensitive to the first 5000 to 10,000 lbs reduction in shuttle payload capability. It should be noted, however, that the missions in the ISPLS model are all payload placement missions. The sensitivity to shuttle payload capability would be different if the model contained payload retrieval missions (see below).

Figure 8.2-4 illustrates the sensitivity of the space-based Concept 2 in terms of shuttle flights required for execution of the program to variations in shuttle cargo weight capability and cargo bay length and to potential growth in the weight and length of the scientific payloads which are placed in orbit in the program. The data show relatively greater sensitivity to cargo bay length and scientific payload length than to shuttle cargo weight capability and scientific payload weight for the indicated changes in the values of these parameters. The data for the 0.892 mass fraction tug are developed on the assumption that a tug of this mass fraction could be operated in space-based concept 2. The length of the space-based tug is 47 feet, whereas the length of the higher mass fraction tug (0.892) is taken as 39 feet.

8.2.1 Retrieval Missions

Calculations were made of the number of payloads in Program Level C, 1985-1990, with 0-30° inclinations which could be placed, retrieved, or carried round trip by each of the three tugs with different mass fractions which are discussed above in Section 8.1. The overall conclusions of this analysis are as follows:

a. The propellant requirements of the relatively heavy "space-based tug" with 0.877 mass fraction are such that a higher mass fraction tug will be required if a retrieval capability is to be economically provided.

b. Space-based operation is the most effective operational mode for the retrieval or round trip capability except for the very highest mass fraction tug (0.903) where ground-based operation is equally effective.

c. The data also indicate that the 0.892 mass fraction tug is nearly as effective as the 0.903 mass fraction tug for the missions in this model.

Tables 8.2.1-1 and 8.2.1-2 present the results of the calculations based on the missions in Program Level C, 0-30° inclinations, 1985-1990. There are 105 payloads in 105 missions in the portion of the program covered by the tables. Of the 105 payloads, the space-based tug with 0.877 mass fraction can place 95 payloads with a single tug. The other 10 either require expenditure of the tug or the use of the two tugs operating in tandem. Similarly, the space-based tug could retrieve 66 of the payloads, or it could carry 66 of them round trip, based on the mission delta-V requirements. The corresponding capabilities of the higher mass fraction tugs are also indicated in Table 8.2.1-1. Each can place 98 of the payloads and retrieve or carry round-trip nearly all of these. The data indicate the advantage of the higher mass fraction tugs over the lower mass fraction tug for the retrieval of payloads or for carrying them round trip.

- PROGRAM LEVEL C 1985 - 1990
- PROPELLANT LOGISTIC CONCEPT #2, 0-30°

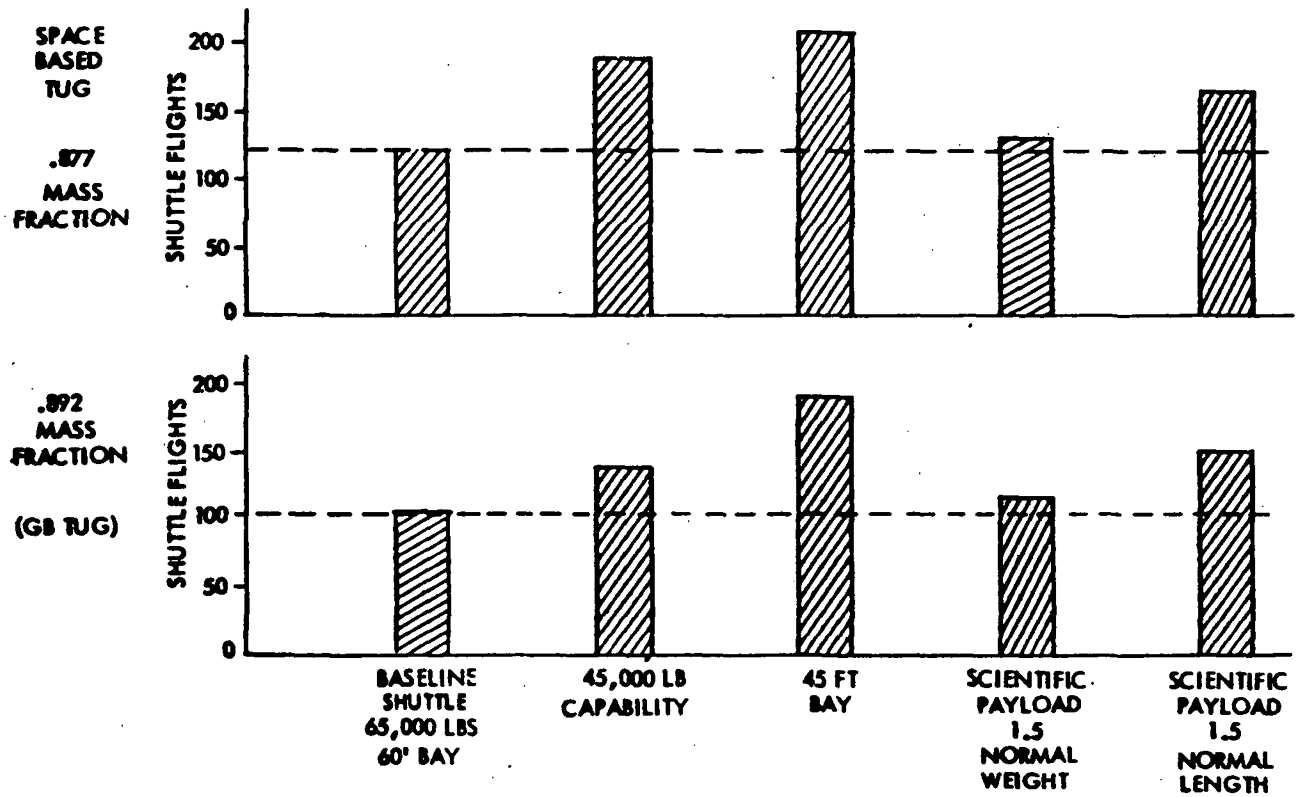


Figure 8.2-4 Summary of Space Based Operational Sensitivities to Shuttle and Payload Variations

Table 8.2.1-1 Payload Placement, Retrieval, and Round Trip Capability Versus Tug Mass Fraction (Program Level C, 0-30°, 1985-1990)

Tug Mass Fraction	Number of Payloads		
	Placed	Retrieval	Carried Round-Trip
0.877 (SB Tug)	95	66	66
0.892	98	93	90
0.903	98	93	93

Table 8.2.1-2 Number of Shuttle Flights Required for Payload, Retrieval Missions by Method of Operation (Program Level C, 0-30°, 1985-1990)

Tug Mass Fraction	Number of Payloads Retrieval	Number of Supporting Shuttle Flights Required			
		Ground Based	Space Based Concepts		
			1 No Storage	2 Self Storage	3 or 4 2 Tugs or Mini-Depot
0.877 (SB Tug)	66	125	119	76	76
0.892	93	108	93	93	93
0.903	93	93	93	93	93

The analysis was extended to determine the number of shuttle flights which would be required to support the retrieval missions which could be accomplished by each tug. The number of shuttle flights required is dependent on the operational concept employed. These data are shown in Table 8.2.1-2. The number of shuttle flights required for the retrieval missions is higher for ground-based operation than for space-based operation except in the case of the very high, 0.903 mass fraction tug.

Table 8.2.1-2 indicates that in space-based operation, either of the higher mass fraction tugs can retrieve or carry on a round trip the same payloads it can place in orbit with only one shuttle flight required for each placement. One shuttle flight for each mission could supply all the needed requirements.

It should be noted that neither the point design tug with mass fraction of 0.903 nor the "ground-based tug" with mass fraction of 0.892 which are used in the study are actually capable of space-based operation. Modification for this purpose would reduce their mass fractions somewhat (see the discussion in Section 8.1).

9.0 SELECTED CONCEPT DESCRIPTION

Propellant logistics concepts to support the space program plan are developed in Sections 4, 5, and 6 of this volume and a cost-effective baseline concept is selected in Section 7. The selected concept is shown in Figure 4.3-5 of Section 4. This section provides a more detailed development of the selected concept. The definition of the propellant logistic module, the description of the logistic operation and the definition of module interfaces with the user vehicles and with the shuttle orbiter are covered. Also included are discussions of maintenance and the role of man. (Description of the ground support equipment is found in Volume IV.) The analysis of the selected concept in this section provides the basis for program development and implementation definition.

The primary hardware element is the propellant logistic module, which carries propellants to earth orbit in the shuttle orbiter to a rendezvous with the user vehicle. The propellant module is deployed and transfers propellant to the user vehicle. The propellant module is described in Figure 9.1-1. It has a hydrogen tank, an oxygen tank; compressors, gas generators for pressurization, and plumbing and controls necessary for transfer of propellants; thrusters with their propellant feed system to provide settling accelerations; a deployment docking fixture at the end which attaches to the shuttle; a user docking fixture at the other end; an outer shell to support the assembly; high-performance insulation to minimize boiloff; and propellant line and control interconnects for transferring propellants to and from the module. (The propellant module relies on the orbiter and user vehicle for control logic and electrical power.) Propellant module line interfaces with the user and the shuttle cargo bay are shown in Figure 9.5.1-4.

The propellant module configuration and operation are essentially the same for all users except for the user docking interface, the size of its propellant tanks, and the amount of propellant transported. Approximately 9300 pounds of LH_2 and 50,900 pounds of LO_2 are carried for the tug; and 11,000 pounds of LH_2 and 49,000 pounds of LO_2 for the CIS, or 29,000 pounds of LH_2 only (which is limited by the volume of the cargo bay) for the alternate RNS interorbital shuttle.

A time line is established (Figure 9.4.2-4) which develops the overall operational sequence of the baseline in sufficient detail to insure the viability of the concept. The propellant logistic module is placed in the shuttle cargo bay in the same manner as any other cargo and filled on the ground. Subsequent to orbital rendezvous of the orbiter with the payload propulsive stage, the propellant module is rotated out of the cargo bay to a position which allows the payload propulsive stage to be docked to the exposed end. The user vehicle-propellant module assembly is separated from the shuttle for the transfer operation. Settling of the propellants is accomplished by a continuous linear acceleration in a direction perpendicular to the shuttle orbit plane. Transfer is accomplished by pumping of the receiver (user) vehicle vapor into the propellant module vapor space, thus pressurizing that tank and causing the liquid to flow to the receiver vehicle. The propulsion system for the settling operation is provided by the propellant module using low thrust engines; the guidance and control of the assembly during the transfer is taken from the

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user vehicle. Subsequent to propellant transfer, the user vehicle-propellant module assembly rendezvous with the shuttle orbiter and the propellant module is redocked and rotated into the cargo bay. If the scientific payload for placement by the user vehicle is part of the shuttle cargo, it is then removed from the cargo bay and docked with the user vehicle.

The baseline concept is very attractive from the standpoint of simplicity of maintenance and the role of man. The propellant logistic module is ground based which allows for maintenance under ideal shop conditions subsequent to any propellant delivery. The subsystems are simple and few. Incorporation of the settling thrust subsystem into the propellant module precludes requiring long-life (long-duration thrust) from a space-based vehicle. The operations are primarily automated, thus minimizing manned support.

9.1 TUG SUPPORTIVE LOGISTIC MODULE

A preliminary definition of the tug supportive propellant logistic module is given in Figure 9.1-1. Since the ISPLS study is not primarily a hardware definition study, this effort is limited to a conceptual definition provided to demonstrate the feasibility of module fabrication and operation. The definition serves as a basis for costing the proposed propellant logistics operations and for establishing the implementation plan. Subsequent design development tasks would review the design and perform the necessary trade-offs to provide optimization of the design.

9.1.1 Basic Module Arrangement and Requirements

The basic design requirements for the tank module are relatively simple and straightforward. The primary function is to carry propellants to orbit and provide for the transfer of those propellants to the tug. The delivery vehicle is the shuttle. The orbiter cargo bay limits the size and capacity of the module and establishes a set of interface considerations. The selected transfer mode is fluid transfer with linear acceleration of both module and tug for propellant settling. This establishes interface requirements for docking and line interconnects with the tug. The requirement to provide the settling thrust has been assigned to the logistic module. To avoid weight penalties to the tug, all the propellant transfer equipment will be in the module. The selected operational mode does not require the module to be a "free flyer" and the decision to have the module draw electric power, data management and communication, and command control support from the orbiter and the tug eliminates these as major onboard systems. Major elements of the module, therefore, are: the structure (shell, tanks and supports); the line interconnect mechanisms; docking systems; thermal protection; propellant transfer system and settling thruster system. The design also includes the support equipment such as the swing-out ring and interface and the cargo bay umbilical and interconnects. Table 9.1.1-1 gives additional design considerations and requirements.

Several design considerations are associated with the location and orientation of the module in the orbiter cargo bay and with deployment based on a swing-out ring. The module will be located aft in the orbiter cargo bay for delivery, allowing about 1/3 of the bay forward of the module for payload sharing. The aft end will be controlled by a swing-out ring during deployment which allows the electrical connections to be maintained until after the docking and interconnections are made to the tug. The swing-out ring provides controlled deployment and support of the module and allows the manipulator arms to control the docking of the tug to the module. The line connections to the orbiter will be made at the aft end of the module and will fit in the aft two feet of the bay already allocated to the deployment ring. Additional use of that space will be made by locating the gas storage bottles for the insulation repressurization and abort dump pressurization systems there. Use of the swing-out deployment ring will require a docking interface between the module and ring to release and reacquire the module; reacquisition will be by a manipulator assisted "soft" docking with the deployed ring. The module will be supported in the cargo bay by appropriate fittings that engage the orbiter cargo retention fittings (the deployment ring will not be a support).

Table 9.1.1-1 Propellant Logistic Tank Design Considerations

General Ground Rules

a. Remote controlled docking and propellant transfer operations.
b. Monitored and controlled from the ground.
c. Monitor override provisions.
d. Observe from shuttle.
e. Shuttle override provisions.

Shuttle Interface

a. The fully loaded and empty tank weight centers of gravity shall fall within the shuttle orbiter cargo bay loading constraints.
b. The envelope of the tank shall be compatible with the shuttle cargo bay dimensions (60' x 15' dia.) with due allowance for loading motions, grasping, and deflections.
c. Mounting fixtures attached to the shuttle shall be considered and shown. Weight allowances for holding fixtures shall be charged to the tank, but listed separately.
d. A line interconnect fixture shall be capable of being connected or disconnected and reconnected by remote mechanical means. The tank module shall be passive in this connection process, and provide all electrical and fluid connection interfaces for both loading/unloading and emergency offload and pressure relief.
e. The tank vent system shall be considered for a capability which precludes venting inside the cargo bay during normal venting or pressure relief.
f. The positioning of attach points for the orbiter manipulators shall be compatible with the extraction process for tank deployment.
g. The tank module should be oriented in the cargo bay such that the propellants are settled toward the same end on the pad as they will be settled during propellant transfer in orbit.

Launch Operations

a. The tank and mounting fixtures shall be designed to withstand the full launch environment.
b. All cryogenics shall be vented via umbilicals to the orbiter in-flight overboard vent system.
c. Venting of unpressurized cavities within the tank structure shall be considered.
d. Provisions shall be made for tank pressurization to suppress boiling during boost and initial orbital operations.

Orbital Hold Operations

a. Cryogenic venting under zero gravity conditions shall be considered.
b. The tank shall be designed for a thermal control system or insulation consistent with the time propellant is stored to assure minimum boiloff.

Figure 9.1-1 Tug Supportive Propellant Logistic Module

Table 9.1.1-1 Propellant Logistic Tank Design Considerations (Cont'd)

Orbital Propellant Transfer Operations

a. The configuration of the docking mechanism shall be considered for compatibility with all possible docking combinations required for propellant transfer.
b. A means of monitoring propellant quantity in the tank during propellant transfer shall be provided.

Return Operations

a. If a multilayer type high performance insulation is used, a means of reintroducing a gas between insulation layers prior to re-entry shall be provided.
b. If any cryogen is remaining in the tanks during re-entry, the tanks must be reconnected via umbilicals to the orbiter in-flight overboard vent system.
c. If a tank is vented to space vacuum, the need for repressurization must be considered. Repressurization will be required to the extent the tank wall is not capable of withstanding external pressure on return. Any venting to space must be done while the tank is attached to the receiver vehicle or a vehicle (other than the orbiter) capable of stabilizing a venting tank.

The basic arrangement of module elements has been determined by interrelated considerations of the cargo bay interface, deployment operations and module and subsystem function. The aft deployment ring obviously dictates that the opposite end of the module be the tug interface with tug compatible docking fixture and transfer line interconnects. The aft location in the bay indicates that the LOX tank should be near the tug interface to keep the module c.g. nearer the center of the cargo bay (see Section 10.0). The thrusters for propellant settling will necessarily be located at the end opposite the tug interface to preclude plume impingement on the tug. The thrusters must fire back along the module to give the correct acceleration direction. Acceleration of the tug will be in the same direction as its normal flight. This will control liquid and ullage to the same ends of its tanks as the onboard fill and vent systems are designed for.

With this acceleration direction established, the aft location of the module and the deployment mode unfortunately dictate that the module will have propellants settled toward the deployment ring end during prelaunch tanking and boost but settling will be toward the opposite end during orbital transfer. (The tug interface end must be the settled end during transfer but this becomes the upper end in the module orientation on the pad). This opposite settling somewhat complicates the tank filling and transfer line system in that fill and vent lines are required at both ends of the tanks. These additional lines and valves are partially offset by the shorter cargo bay umbilical that results from the aft location choice. The more favorable deployment and tug docking location (within manipulator reach) also influenced the aft location decision. Location of the payload in the forward part of the bay may also be

preferable in that it might be more easily reached and handled by the manipulator arms and in that a forward payload would be accessible via the crew transfer tunnel from the orbiter cabin, should that be necessary.

9.1.2 Structure

As is shown in Figure 9.1-1, the tug supportive logistic module is comprised of an outer shell structure within which the oxygen and hydrogen tanks are suspended. The shell is the primary load carrying structure and functions as a purge bag and meteoroid shield as well. The shell is of approximately 0.4 inches thick composite material: aluminum honeycomb core and graphite epoxy face sheets. The cylindrical portion of the shell is 178 inches in diameter, allowing the module with slight deflection and possible external protuberances to stay within the 180-inch cargo envelope limit. The cargo attach fittings extend beyond the envelope limits as is required to engage the orbiter cargo retention fittings. The cylindrical and the truncated portions of the shell are stiffened by ring frames with relatively deep frames at intersections of these portions and at the station where the LH_2 tank is supported. Reinforcements are also provided at the cutouts in the shell structure, such as where the transfer line interconnects, settling thrusters and cargo bay line receptacle installations interrupt the normal contours of the shell. Additional access panels are located both in the end portions of the shell and in the area between the tanks. A field break is also provided between the tanks for access for major maintenance.

The ends of the shell structure terminate in docking fixture support structure. At the tug docking end an 84-inch diameter aluminum ring is provided to interface with similar structure on the forward end of the tug. Suspended within this ring is the Apollo drogue fitting. Closeout structure isolates the drogue and docking recess from the interior of the module. The Apollo probe on the tug provides the docking attenuation and capture and has the capability of drawing the vehicles together. Additional structural attachment for docked vehicles or payloads was not detailed on the tug definition. This attachment is provided by a series of attach latches on the outside of the docking ring (locating them outside permits external accessibility). Unless required on the tug for other (payload) attachment, the latches would be on the logistic module to reduce tug mass and to provide for maintenance on the ground. The Apollo docking system will be augmented by alignment fittings located at the docking ring which will index the module and the tug with respect to roll orientation (a feature lacking on Apollo which is necessary here to assure alignment of the line interconnects).

A similar 84-inch diameter docking ring is shown at the other end of the module. This docking interface is between the tank module and the deployment ring. Since both are elements of the propellant logistics cargo, the interface does not require coordination between separate vehicle design efforts. It is anticipated that similar docking applications will lead to development of suitable "standard" fixtures. (The probe and drogue fixtures shown here were also proposed on an NR ground-based tug study.) The three actuated probes extend from the deployment ring to engage three recessed, conical

drogues within the ring on the module. The extended probes are free to deflect and thus engage the sockets when initial contact is made between misaligned fittings. After capture, the probes retract and guide the module into close alignment with the deployment ring. Attachment latches are shown around the outside of the ring. Since the swing-out ring is for zero-g deployment only and the retention fittings transmit flight loads directly from the module shell to the orbiter, the loads across this deployment interface are slight.

The deployment ring, though not an integral part of the module, is part of the logistic cargo and would be included with the module design. The ring can also be of composite honeycomb structure. The seven-foot diameter ring allows service line connections (cargo bay line interfaces) to be external to the ring and accessible after the module is installed in the cargo bay. The hinge point location is high in the bay so that the deployed ring will provide ample clearance between the module and orbiter structure for return docking. The active interconnects (redundant pair) for the electrical bundles are attached to the deployment ring. The cargo bay electrical umbilicals are installed so that they can flex during deployment and thus allow the electrical service to remain connected after deployment (and until these functions are taken over by the tug). The storage bottles for repressurization of the multi-layer insulation (MLI) and for tank pressurization for abort dump are also attached to the deployment ring. The line connections are included in the interconnect for the electrical bundles. (Since the bottles move with the ring for deployment, no flex gas lines are needed.) A mechanism is included that retracts the hinge pins during flight in the orbiter to preclude the transmission of any loads between ring and orbiter.

The tanks are sized to hold propellants up to the full 65,000 lb shuttle cargo capability. A tank module weight of 4,000 lb was assumed and an additional 800 lb allowed for the swing-out ring and other cargo bay installations. The ratio of LOX and LH_2 takes tank residuals and LH_2 boiloff into consideration such that the module leaves the launch pad not with the 6:1 tug burn ratio but with a ratio that gives 6:1 delivered into the tug tank. (Tug boiloff losses were not included but subsequent development of logistic module design could also consider further optimization of the lift-off ratio to result in the correct burn ratio at the time of usage.) The resulting tank volumes, with allowances for ullage and internal structure, are 750 cubic feet for the LOX tank and 2,300 cubic feet for LH_2. These give tank capacities of 50,900 lb LOX and 9,300 lb LH_2. In the payload sharing concept of payload placements by the tug, the tanks would fly off-loaded by the amount of payload weight but have the full capacity for those flights when only propellant is to be delivered.

The propellant tanks are aluminum, made from formed, machined panels butt-welded together. The LH_2 tank is 162 inches in diameter and 234 inches long. It has oblate spheroid ends and a 118-inch cylindrical section. Using a reversed bulkhead on the inboard end of the hydrogen tank was considered. That would present a concave face to the oxygen tank to allow nesting of the tanks and would somewhat reduce LH_2 residuals by eliminating fluid "pull-thru" problems of a large diameter, relatively flat ended tank. However, the nested tanks would diminish accessibility between tanks and would force the LOX drain line to run uphill out of the nested area on its way toward the

swing-out ring end of the tank. Because the LH_2 is such a low density liquid the reduced residuals of the reversed bulkhead would approximate only 100 lb. (See Section 6.0 in Volume III.) Since this would likely be more than offset by the increased weight of a structurally inefficient reversed bulkhead, the bulkhead as shown was selected.

The LOX tank has an oblate spheroid inboard end of the same ratio as the LH_2 bulkheads. The settled end of the tank (during propellant transfer) is a 90° (included angle) cone to reduce residuals. The tank is 150 inches in diameter and 144 inches long. Both tanks have access doors. The LH_2 tank access is centered in the outboard bulkhead opposite the closeout access panel within the shell end ring. The LOX access is off center in the spheroidal bulkhead near a panel in the shell that provides access to the area between the tanks. Both tanks are completely covered with MLI (described in a subsequent paragraph). Propellant transfer lines are routed next to the tanks within the tank insulation, and/or they are appropriately insulated to keep them at cryogenic temperatures to reduce line chill-down boiloff losses.

The tanks are supported within the shell by a series of support struts. The struts are S-glass filament wound composite tubes. These give the required strength with a minimum cross section and low thermal conductivity material to minimize the heat leak through the struts. Strut ends are mounted with spherical bearings to permit the change in alignment necessary for tank thermal contraction. The LOX tank is suspended from the intersection of the cylindrical and conical portions of the shell where a major structural ring is already required. The struts attach to the tank at the intersection of the spheroidal bulkhead.

The LH_2 tank is suspended from another major stiffener ring of the shell. This ring is also part of the field break in the outer shell. Struts attach to the tank at the intersection of the inboard spheroidal bulkhead and the cylindrical portion of the tank. The LH_2 tank also has a series of secondary radial struts at its outboard end. These struts will stabilize the tank under lateral loads such as during landing. The struts attach just outboard of the access door in the center of the tank end bulkhead. Struts are normal to the tank centerline and will assume a slight angle due to lengthwise thermal contraction of the tank.

The primary tank support struts are also angled as seen in an end view (rather than on radial lines). This gives a better distribution of lateral loads. It also makes the struts longer which helps reduce heat transfer through the struts. The support struts of both tanks are in tension during loading and boost. The module is supported in the cargo bay by the external fittings shown on the shell. Flight loads are primarily carried by the two side trunion fittings that are in about the same plane as the inboard end of the LOX tank. The major mass of the module, the filled LOX tank, will thus transmit a distributed load into the shell structure which will, in turn, be reacted at the two side fittings. The segment of the shell between the LOX tank struts and the side fittings will be in compression and must be sufficiently long to allow the distributed load to concentrate at the fittings.

To complete the tank module description, the other major components shown on the figure will be identified; the systems will be described in subsequent paragraphs. A majority of the systems equipment will be located between the LOX tank and the tug interface end of the module. The transfer system pumps and heat exchangers are shown there. The LOX and LH_2 accumulator tanks that provide high pressure gas storage for settling thrusters and transfer system start-up are there. Also, the transfer line interconnects, capable of extending and connecting the lines to the user, are at that end of the module. Similar interruptions in the conical shell at the other end of the module are for the receptacles to which the cargo bay interface lines are connected. The four larger housings at that end contain the settling thrusters. The thrusters are on deployable units that extend beyond the 15-foot diameter cargo envelope and fire aft along the module in use. The use of two thrusters (a diagonally opposite pair) is sufficient for propellant settling; the other pair provides redundancy.

9.1.3 Interconnect Mechanisms

The transfer line interconnects extend the fluid lines and electrical connectors from the propellant module to the tug. They are located outside the docking ring with the LOX line interconnect diametrically opposite the one for LH_2 and electrical connectors. A second pair of identical interconnects is shown for redundancy. Each interconnect is designed and installed as a modular unit containing the extension mechanism, bellows for line extension, alignment guides, and engagement probes with check valves. The face of the interconnect is recessed 6 inches behind the docking interface plane. Assuming the receptacles in the tug will be similarly recessed (not over 8 inches), an approximate 16-inch extension capability will be provided, including the insertion into the receptacles. A cover will shield the extendable housing and probes when not in use. The cover will revolve in plane to allow opening after the tug is docked.

In operation, the interconnect housing will extend, bringing the probes with it (extending the bellows) until the three alignment pins engage the alignment receptacles. The housing is mounted with floating capability to permit angular and lateral shift for proper alignment as the pins are engaged. When fully engaged the housing will latch to the tug receptacle housing. Separate extension drives will engage the electrical connectors and the fluid lines separately after housing alignment.

9.1.4 Thermal Protection

The thermal protection system consists of insulating and isolating the propellant tanks and of utilizing thermodynamic vent coils to remove heat from the tanks. Both the LH_2 and the LOX tanks are completely covered with 1 inch of MLI. The insulation material assumed is embossed and perforated aluminized Kapton film. It is applied in a series of 5 shield panels with staggered seams to build up the 60 shields required. The MLI is supported on the propellant tanks with posts molded from epoxy/fiberglass. The posts are hollow to minimize heat leak. At each post location a foam-filled phenolic honeycomb hardspot is bonded to the tank surface. A threaded insert is bonded into each hardspot, which accepts the MLI support post.

In order to effectively purge the MLI from the back side, a 1.00-inch annulus is provided between the propellant tank and the insulation. The internal purge manifold is located in this annulus. It distributes purge gas at balanced pressure through the annulus, permitting even flow through the MLI. The MLI is spaced away from the tank surface on an aluminum wire mesh supported by the foam/honeycomb hardspots. Threaded fasteners are used to attach the mesh to inserts in the hardspots. The mesh is installed in stretch-formed segments with cutouts provided for all MLI penetrations. The annulus is sized to assure even distribution of the purge gas and to afford clearance between the MLI and irregular shapes on the tank surface. An external tension membrane of Nomex mesh is provided to contain the MLI during purge and preconditioning operation when backside pressure forces are being exerted, and to protect the insulation surface from mechanical damage.

The tank support struts, of low conductivity material, help to thermally isolate the tanks from the remaining module structure. These struts are described in the structure section (9.1.2). The thermodynamic vent is explained in the following section.

9.1.5 Propellant Transfer and Settling Thrust System

The selected baseline configuration incorporates separate linear acceleration of the user vehicle/logistic module for liquid/vapor interface control connected user/logistic module ullage for receiver tank thermodynamic control, gas pump in the ullage return line for liquid expulsion, and a turbopump heat-exchanger supercritical system for NPSP control of both propellants and to feed the gaseous oxygen-hydrogen acceleration thrusters.

The system components required to support the fluid transfer operation are incorporated into the logistic module configuration. Concentration of this equipment in the logistic module eliminates the payload penalty associated with transporting component weight on tug payload placement missions, eliminates the need for in-space maintenance of components and eliminates or minimizes the configurational impact upon the user vehicles.

Figure 9.1.5-1, a conceptual system schematic, shows the components and lines required for the logistic module for servicing the space-based tug and the CIS. An all LH_2 tank using the same conceptual design would be required for servicing the RNS. Table 9.1.5-1 lists the components and provides preliminary weight and sizing information for the tug supportive logistic module. Component key numbers are listed to allow correlation of the components with the schematic. The schematic shows the configuration oriented in the ground loading and launch attitude. For in-space transfer operations the linear thrust is applied in a direction to settle the LOX into the conical sump of the tank.

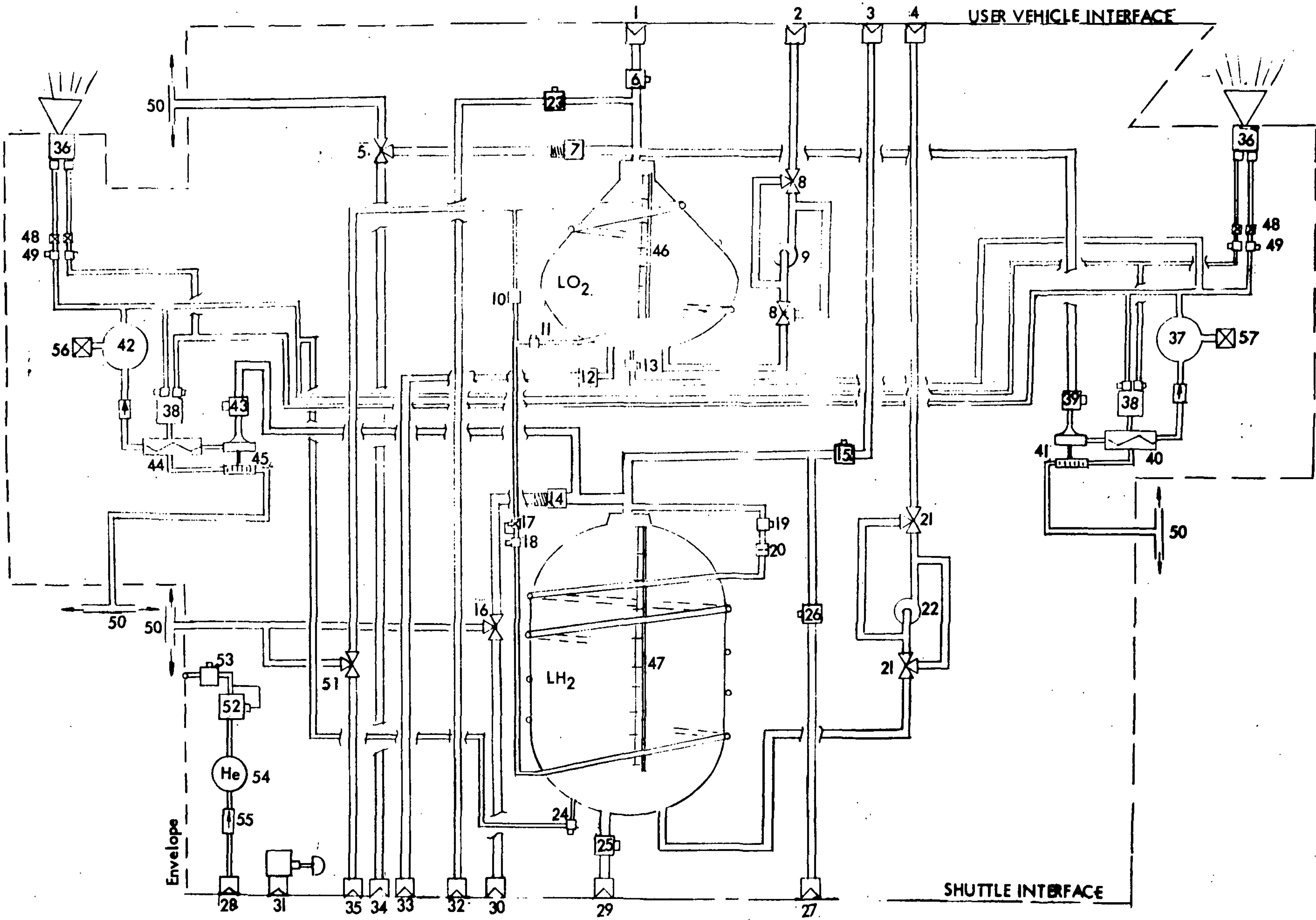

Figure 9.1.5-1 Logistic Tank Systems Schematic
(Tug Supportive)

Key numbers 1 through 4 of Figure 9.1.5-1 and Table 9.1.5-1 represent the fluid transfer elements of the logistic module /user vehicle interface. Key numbers 27 through 35 represent the fluid elements required to interface the tank with the orbiter. The orbiter interface will provide for all the "in the bay operations", including the fill, vent and drain functions on the ground, and vent and emergency dump function for boost operations.

After the logistic module has been deployed, logistic module to user docking completed, the fluid interface connections verified, and the orbiter separated from the logistic module/user, the fluid transfer cycle is initiated.

The propellant transfer functions of the baseline configuration are as follows. The two gas generator assemblies (38) and valves 39 and 43 will be energized open, causing LOX and LH_2 to flow into the gas generator driving the LH_2 and LOX turbopumps 45 and 41. High pressure LOX and LH_2 from the turbopumps is passed through the heat exchangers 40 and 44 to the accumulators 42 and 37. The pressure level of the accumulators is maintained in the operating band by cycling the turbopumps, as required. After operational pressure level is established in the accumulators, the propellant valves in the thrusters are energized open and thrust is generated for use in cross-plane linear acceleration. Recharging of the accumulators will occur while propellant is settled such that liquid can be delivered to turbopumps 41 and 45. Zero-g starting of the thrusting system can be accomplished by drawing gas from the accumulators which could have been charged on the ground through ground fill valves 56 and 57.

Propellant tank NPSP is provided by routing pressurized oxygen and hydrogen gas from the accumulators to the respective tank pressure-control valves 13 and 24. Three-way valves 8 and 21 are positioned to interconnect the ullages of the receiver and logistic tanks during the initial NPSP pressurization cycle. After tank pressure levels within the NPSP requirements of the receiver vehicle have been established, valves 8 and 21 are repositioned to route gas from the receiver through the pump to the logistic tanks. The pumps are energized and the transfer flow control valves 6 and 15 are positioned for chill down flow rates. After chill down is accomplished, valves 6 and 15 are positioned for the design transfer flow rates. Valves 6 and 15 are modulating valves and provide the flow control required for chill down and 10 to 1 throttling capability used during the final portion of the propellant transfer cycle to improve the tank feed out characteristics.

The gas pumps and valve clusters also have the capability of reverse propellant flow for detanking the user for emergency or abnormal conditions.

At the conclusion of the transfer cycle, the pumps 9 and 22 are shut down and the valves 6 and 15 are closed. The independent operational mode is established for the logistic tank and user vehicle propellant systems. The cross plane thrusters will remain in operation until the logistic module and user vehicle reach the closest point with the orbiter parking plane. At this time the linear acceleration thrusters will be shut down and rendezvous operation with the orbiter will be initiated.

Table 9.1.5-1 Tug Supportive Logistic Tank System Components

Name	No.	Size (in)	Weight (lb)	Pressure (psia)	Temperature (R)
LO_2 Transfer Disconnect	1	1-1/2	4	22	163
LO_2 Ullage Interconnect Disconnect	2	3/4	3	22	163
LH_2 Transfer Disconnect	3	1-1/2	4	22	37
LH_2 Ullage Interconnect Disconnect	4	3/4	3	22	37
LOX Vent Selector 3-Way Valve	5	3	8	22	163
LO_2 Transfer Flow Control Valve	6	1-1/2	4	22	163
LO_2 Tank Fill Vent & Emergency Relief Valve	7	3	8	22	163
LO_2 Ullage Interconnect Three-Way Valve	8	3/4	3	22	163
GOX Pump	9	1	5	1250	163
TVS LO_2 Tank By-pass Valve	10	1/2	2	22	37
TVS LO_2 Tank Shutoff Valve	11	1/2	2	22	37
LO_2 Fill, Drain & Emergency Dump Valve	12	3	8	22	163
LO_2 Tank Pressure Control Valve	13	1	4	22	163
LH_2 Tank Fill Vent & Emergency Relief Valve	14	3	8	22	37
LH_2 Transfer Flow Control Valve	15	1-1/2	4	22	37
LH_2 Vent Selector 3-Way Valve	16	3	8	22	37
TVS Back-Pressure Regulator	17	1/2	2	22	37
TVS Shutoff Valve	18	1/2	2	22	37
TVS Shutoff Valve	19	1/2	2	22	37
TVS Expansion Valve	20	1/2	2	22	37
LH_2 Ullage Interconnect Three-Way Valve	21	3/4	3	22	37

Table 9.1.5-1 Tug Supportive Logistic Tank System Components (cont'd)

Name	No.	Size (in)	Weight (lb)	Pressure (psia)	Temperature (R)
GH_2 Pump	22	1	5	1250	37
LO_2 Ground Pressure Control Valve	23	1	4	22	163
LH_2 Tank Pressure Control Valve	24	1	4	22	37
LH_2 Fill, Drain & Dump Valve	25	3	8	22	37
LH_2 Ground Pressure Control Valve	26	1	4	22	37
LH_2 Tank Purge & Drain Press Disconnect	27	1	4	22	37
Insulation Purge Disconnect	28	1/2	2	22	37
LH_2 Fill, Drain & Emergency Dump Disconnect	29	3	8	22	37
LH_2 Tank Vent Disconnect	30	3	8	22	37
Insulation Cavity Vent Valve Disconnect	31	1	4	22	37
LO_2 Tank Purge & Drain Press Disc	32	1	4	22	163
LO_2 Fill, Drain & Emergency Dump Disconnect	33	3	8	22	163
LO_2 Tank Vent Disconnect	34	3	8	22	163
TVS Vent Disconnect	35	1/2	2	22	37
Settling Thruster	36	(2 lb)	5	250	400
GOX Accumulator	37	(500 in^3)	15	1250	1200
Gas Generator Assembly	38	1/2	8	250	1500
LO_2 Heat Exchanger Shutoff Valve	39	1/2	2	22	163
LO_2 Heat Exchanger	40	1/2	8	1250	1500
LO_2 Turbopump	41	1/2	8	1250	163
GH_2 Accumulator	42	(500 in^3)	15	1250	1200
LH_2 Heat Exchanger Shutoff Valve	43	1/2	2	22	37

Table 9.1.5-1 Tug Supportive Logistic Tank System Components (cont'd)

Name	No.	Size (in)	Weight (lb)	Pressure (psia)	Temperature (R)
LH_2 Heat Exchanger	44	1/2	8	1250	1500
LH_2 Turbopump	45	1/2	8	22	37
LO_2 Gauging System	46	-	8	22	163
LH_2 Gauging System	47	-	8	22	37
Thruster Shutoff Valve	48	1/2	2	250	1500
Thruster Flow Control	49	1/2	2	250	1500
Non-Propulsive Overboard Vent	50	1/2	2	50	600
TVS Vent Selector 3-Way Valve	51	1/2	2	22	163
Insulation Purge Regulator	52	1/2	2	25	600
Insulation Purge Shutoff Valve	53	1/2	2	25	600
Insulation Purge Helium Storage Vessel	54	(6 ft^3)		3000	
Insulation Purge Check Valve	55	1/2	2	3000	600
GH_2 Accumulator Ground Fill Valve	56	1/2	2	1250	600
GOX Accumulator Ground Fill Valve	57	1/2	2	1250	600

Note: TVS - Thermodynamic Vent System

The thermodynamic vent system (TVS) shown on Figure 9.1.5-1 has been included to insure acceptable tank pressure levels at all times and to minimize propellant loss by utilization of the temperature change of the vented hydrogen to cool the propellant and tank hardware. Liquid or vapor hydrogen is routed from the LH_2 tank sump outlet through shut-off valve 19 to the expansion valve 20. As the fluid is expanded through the valve, the pressure and temperature drop. The resultant two-phase fluid is routed through the hydrogen tank cooling tubes absorbing heat energy by enthalpy change as the fluid expands and changes state. Regulator 17 controls the pressure down-stream of the LH_2 tank cooling tubes. The cold vent fluid is then routed to the LOX TVS control valves 10 and 11, where the fluid is by-passed through the LOX tank cooling tubes or routed directly overboard as required to control the LOX tank system conditions. No venting of the LOX tank is required.

Vent selector 3-way valves 5, 16, and 21 will be positioned to route vent gases to the non-propulsive overboard vents 50 during orbital operation. When the logistics module is in the orbiter cargo bay, vented gases will be routed to the cargo bay interface disconnects 34, 30, and 35, respectively, for safe disposal.

9.2 CIS SUPPORTIVE LOGISTIC MODULE

The selected propellant logistic concept for refueling the CIS is also direct transfer from a tank module and self-storage in the CIS. Propellants are delivered in a tank module (with propellant transfer capability) that is carried to the CIS parking orbit by the shuttle. In this case, the CIS accumulates propellant over a span of 19 shuttle flights before its tanks are completely filled. As was outlined for the tug, the transfer mode is to attach the logistic module to the CIS, release it from the orbiter and provide a linear acceleration of the CIS and the module for propellant settling. The logistic module for CIS support is shown in Figure 9.2-1. This module is very similar to the tug supportive module and the following definition will be limited to describing the differences.

9.2.1 Basic Module Arrangement and Requirements

The CIS logistic operations set the same basic requirements for module systems and functions as were outlined for the tug supportive module. The CIS supportive module will carry LOX and LH_2 in the correct ratio (considering losses) to supply a 6:1 ratio to the CIS and will utilize the full 65,000 pound capability of the shuttle. The module will draw power, data management, etc. from the shuttle and the CIS and will contain all of the propellant transfer related components. It will provide the thrusters for propellant settling. The module elements and their arrangement are the same as for the tug supportive module as is the location and orientation of the module in the cargo bay. Deployment of the module and docking to the CIS are assumed to be essentially the same as for the tug supportive module, with the possible exception that the CIS module may be deployed to a greater angle out of the cargo bay to provide additional clearance for docking of the larger diameter CIS.

Figure 9.2-1 CIS Supportive Propellant Logistic Module

The two basic differences in the CIS module from the tug module are the different requirements in LOX to LH_2 ratio and in the user docking interface. The CIS supportive tank module will leave the ground with a significantly higher proportion of LH_2, even though both tug and CIS use propellant at the same (6:1) ratio. This additional hydrogen will make up for the LH_2 boiloff from the CIS tanks during the extended time required for the filling process. The additional LH_2 will require a longer hydrogen tank and the overall length of the module will increase a corresponding amount. Since the difference in tanks justifies (see following paragraph) separate (but similar) modules for tug and CIS, there is no requirement for common docking fixtures or adapters. The CIS docking port on the module will correspond to the fixture as proposed on the ISPLS baseline CIS configuration.

The CIS and the tug could be served by a common module, but it is felt that unique modules with a maximum of design and component commonality are the proper approach. The tank modules would share most structure and components and would be designed as a model change where the CIS model LH_2 tank would have a cylindrical segment added, as would the outer shell. The docking ring could be the same but would have a different docking fixture installed. Were a common module used, it would have the longer hydrogen tank and fly off-loaded on tug missions. This would be detrimental to the payload sharing concept where the longer module would preclude simultaneous delivery of some of the longer payloads. The costs of extra logistic flights thus caused could outweigh any advantage of using a common module. The solution to common docking (or use of adapters) that would be required by the common module would also be a penalty. A heavier docking fixture imposed on the tug for propellant logistics commonality would be costly in reduced tug performance.

9.2.2 Structure

The CIS propellant module structural concepts are the same as for the tug supportive module and all the rationale presented in Section 9.1.2 applies except for the LH_2 tank and module lengths, the docking fixture and the line interconnect locations.

The LH_2 tank is 22 feet long (2 1/2 feet longer than in the tug module) and is sized at 2,700 cubic feet for a capacity of 11,000 pounds. Because of the added tank and module length, a total weight (including cargo bay installation) of 5,000 pounds was assumed. The LOX tank would thus need a 49,000 pound capacity. This would make an optimum tank size of only about 25 cubic feet smaller than the LOX tank for the tug supportive module. For this small difference, it is recommended that the LOX tank be common to both modules. As shown in the Figure 9.2-1, the module length is 40 1/2 feet.

The docking fixture is the passive ring cone to correspond to the fixture shown on the baseline CIS.

9.2.3 Interconnect Mechanisms

Line interconnects are the same as for tug, with the same line sizes and arrangement. The location of the interconnects is changed to agree with the

CIS. The CIS propellant line receptacles will have to be located further outboard of the docking ring because of the support truss structure on the CIS. (This is illustrated in Figure 9.5.2-5)

9.2.4 Thermal Protection

The MLI, tank support struts and thermodynamic vent descriptions of Section 9.1.4 are the same for the CIS supportive logistic module.

9.2.5 Propellant Transfer and Settling Thrust System

The propellant transfer configuration and system operation for the CIS supportive logistic module is essentially the same as for the tug supportive system with the exception of sizing of the linear thrusters. A total of eleven pounds thrust is necessary to provide the force required for the liquid/vapor interface control for the CIS module, and a total of 7.5 pounds thrust is required for the tug supportive module. The system schematic, component list and system operation description given in Section 9.1.5 are also applicable to the CIS module.

9.3 RNS SUPPORTIVE LOGISTIC MODULE

Direct transfer from the propellant module and self-storage is the selected logistic concept for refueling the RNS. The shuttle delivers the propellant module to the RNS orbit, the module is transferred to the RNS and fluid transfer of the propellant takes place during the linear settling acceleration. The RNS main engine uses LH_2 only, making the propellant module significantly different from one for a tug or CIS. Here, the module is essentially all LH_2 tank, and the size of the cargo bay limits the LH_2 capacity rather than shuttle cargo weight capability. LH_2 capacity is about 29,000 pounds requiring about 11 shuttle flights to fill the RNS. (Preliminary estimates indicated that approximately 34,000 pounds of LH_2 would be the maximum capacity of an optimum configuration propellant module, and this figure was used in determining shuttle flights and costs of supporting RNS. Subsequent selection of direct transfer imposes the requirement for transfer equipment such as the interconnect mechanisms, which usurps space in the module. Also, the use of a deployment ring and deployment clearances use space in the bay and reduce the module overall length. These factors, plus a closer look at and slightly conservative approach to the module design have resulted in the lower capacity.) The RNS supportive propellant module is shown in Figure 9.3-1. Although the RNS supportive module looks somewhat different from the tug supportive module, most of the descriptions and rationale of the tug module definition apply here. The following RNS module definition will describe the differences.

9.3.1 Basic Module Arrangement and Requirements

The basic difference in requirements is the delivery of essentially all LH_2 to the RNS. The propellant module fills the orbiter cargo bay and the LH_2 tank nearly fills the module shell. A small amount of LOX will be delivered for use in the RNS attitude control system and fuel cells. Operationally, the logistic concept is the same for RNS support as it is for tug support. The

Figure 9.3-1 RNS Supportive Propellant Logistic Module

module will draw power, data management, etc. from the shuttle and the RNS, will contain the transfer equipment, and will provide the thrust for linear acceleration settling of the propellant. Deployment and docking will be the same as with the CIS supportive module.

9.3.2 Structure

The propellant module is 56-1/2 feet long, leaving room in the cargo bay for the deployment ring and clearance for the module to swing out. The shell is the same diameter and construction as the other modules, but is longer and has a steeper conical section at the RNS docking end. The LH_2 tank is the same diameter and construction; it could share the manufacture of bulkheads and cylindrical segments with a tug supportive LH_2 tank, using additional segments to make up its 50-1/2 feet length. The LH_2 tank shown has a volume of 6800 cubic feet and holds 28,500 pounds. The tank is supported by struts at both ends in a manner similar to the tug module LH_2 tank although these supports may be of different lengths and orientations. The LOX tank is a 2-1/2-foot diameter sphere that holds 600 pounds. The tank module weight, including deployment ring and cargo bay umbilicals, etc., is estimated at 6000 pounds.

The deployment ring will be the same as for the tug supportive module. The requirement to dump propellant in an abort mode does not apply since the launch weight of the loaded propellant module is less than the 40,000-pound limit. This eliminates the requirement for stored gas for tank pressurization. However, since the MLI repressurization requirement increases due to increased tank length, the same number of pressurization bottles are shown. Because of the small quantity of LOX on-board, the LOX fill and drain line can be 1 inch I.D. (rather than 4-inch I.D.). For commonality, the interface with the cargo bay umbilical can remain the same. The docking fixture is the passive ring cone that would be compatible with the fixture shown on the ISPLS baseline RNS.

9.3.3 Interconnect Mechanisms

The propellant transfer line interconnects for the RNS supportive module would be of the same design and operate the same as those described for the tug supportive module. The one difference would be the size of the transfer lines in the LH_2 interconnect. Because of the large quantity of LH_2 to be transferred and its low density, a larger line is used. The 2-1/2-inch diameter line shown will permit LH_2 transfer within the 5 to 15 hour transfer period using a reasonable (less than 1 HP) gas pump motor.

9.3.4 Thermal Protection

The MLI installation and LH_2 tank support struts are the same for the RNS supportive module as those defined for the tug supportive module. A simple arrangement of the S-glass struts, as shown in Figure 9.3-1, is sufficient to support the small LOX tank.

9.3.5 Propellant Transfer and Settling Thrust System

The LH_2 propellant transfer system and system operation for the RNS supportive logistic module are the same as those used for the tug supportive module except that larger LH_2 supply and gas return lines are needed to replenish the all-hydrogen propulsive tank of the RNS. A 2 1/2 inch diameter supply and 1 1/2 inch diameter gas return is needed for the RNS; these lines on the tug supportive module are 1 1/2 and 3/4 inch diameter, respectively. Also, the linear thrusters are sized for four pounds total thrust for the RNS in contrast to the 7.5 pounds total thrust required for the tug. The LH_2 portion of the system schematic, component list, and system operation description given in Section 9.1.5 are also applicable to the RNS module. A small utility LOX transfer capability will also be required to replenish the oxygen for RCS and fuel cell function of the RNS.

9.4 OPERATIONAL CONCEPT

A concept for the total recommended propellant logistics operation is outlined in the following paragraphs. This concept is based upon the use of the previously described logistic module using the Operational Concept for Payload Delivery No. 2 (space-based tug without an orbital storage facility, tug in 180 x 180 nautical mile orbit, fluid transfer). A concept for propellant delivery to a CIS or RNS is not presented; however, it would be very similar to that discussed for the space-based tug.

Pre-flight operations (checkout, mating, erection, propellant loading and launch countdown) and post-flight operations (safing, securing, drain and purge, logistic module unloading, and checkout) are discussed in Section 9.4.1 with the associated time lines shown in Figures 9.4.1-1 and 9.4.1-2.

The in-flight event sequence (including deployment and propellant transfer) is discussed in Sections 9.4.2 through 9.4.4 and the associated time line is shown in Figure 9.4.2-4. The in-flight concept is set up for the orbiter to return to earth within 48 ± 3 hours after liftoff, with the space-based tug located in a 180 nautical mile orbit with a period of approximately 90 minutes.

9.4.1 Ground Operations

The development of a ground servicing operational concept for both pre-flight and post-flight functions of the logistic module activities has been predicated on providing a time line schedule compatible with the total integrated shuttle ground operations plan. Figure 9.4.1-1 presents the shuttle orbiter, booster, logistics tank, and payload pre-flight ground operations (event, sequence, and time line) for payload delivery, and consists primarily of the following:

a. The orbiter, logistic module, and booster premate checkout functions will be performed during the premate period, and will provide the basic confidence that the orbiter and logistics tank subsystems have withstood transportation and/or the previous flight and are capable of supporting another mission.

b. The orbiter will be moved to the mating area and the cargo bay set up for receipt of the logistic module and payload modules. GSE handling and facility hoisting equipment will then be utilized to install these modules in the cargo bay. Next, interfaces will be connected and verified by performing continuity and pressure tests.

c. The orbiter will be raised to the vertical position and mated to the booster.

d. All ordnance will be installed and verified, and umbilicals installed and verified. The logistic module propellant, pneumatic, and electrical systems are connected from the module to the orbiter installed umbilicals.

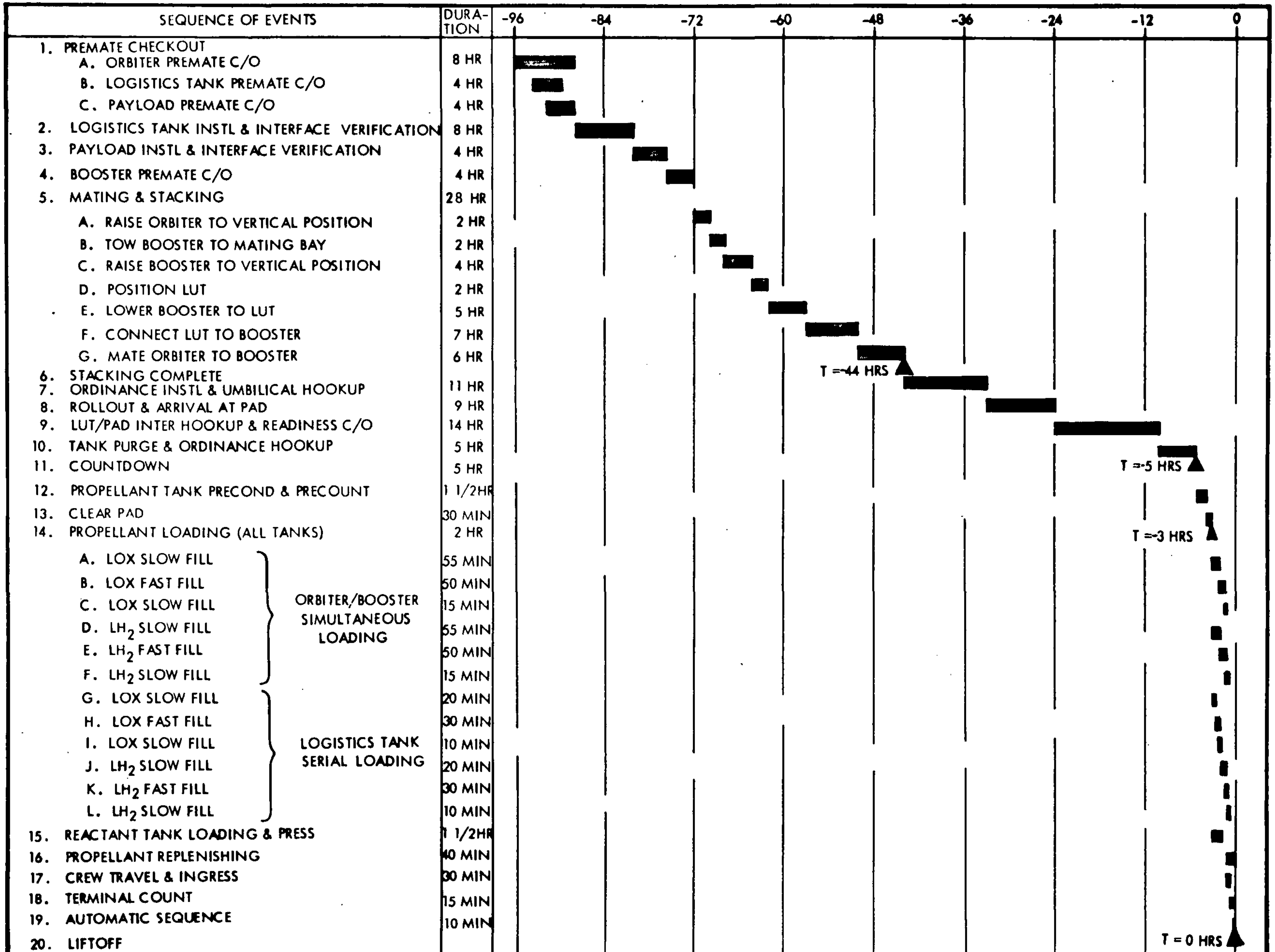

Figure 9.4.1-1 Pre-Flight Ground Operation Sequence

SEQUENCE OF EVENTS	DURATION
1. LANDING COMPLETE (T=0)	
2. TOW ORBITER TO SAFING AREA	(1HR)
3. SECURE ORBITER & REMOVE FLIGHT PERSONNEL & FLIGHT DATA	(3HR)
A. PERFORM ONBOARD SAFING	(30MIN)
B. PERFORM POSTFLIGHT SECURING	(45MIN)
C. POSITION PLATFORMS	(15MIN)
D. REMOVE FLIGHT PERSONNEL	(30MIN)
E. REMOVE FLIGHT DATA	(30MIN)
F. TRANSMIT DATA TO ANALYSIS AREA	(30MIN)
4. PERFORM POSTFLIGHT SAFING	(7HR)
A. POSITION MAINTENANCE PLATFORMS	(15MIN)
B. COOL THERMAL PROTECTION SYSTEM	(2HR)
C. PERFORM PRELIMINARY EXTERIOR INSPECTION	(1HR)
D. ATTACH DRAIN, VENT & PURGE LINES	(30MIN)
E. DRAIN RESIDUAL PROPELLANTS (ORBITER & PROPELLANT TANK)	(30MIN)
F. VENT HIGH PRESSURE GASES	(30MIN)
G. PURGE PROPELLANT TANKS (ORBITER & CARGO PROPELLANT TANK)	(1HR)
H. REMOVE DRAIN, VENT & PURGE LINES	(30MIN)
I. INSTALL PROTECTIVE COVERS	(30MIN)
J. REMOVE MAINTENANCE COVERS	(30MIN)
K. SECURE SYSTEMS & REMOVE GROUND SERVICES	(1HR)
5. TOW ORBITER TO HANGAR AREA	(2HR)
6. PREPARE FOR HANGAR OPERATIONS	(1HR)
7. UNLOAD PROPELLANT TANK (CARGO)	(24HR)
A. OPEN CARGO ACCESS DOORS	(30MIN)
B. INSTALL CARGO HOISTING MECHANISM	(30MIN)
C. DISCONNECT PROPELLANT TANK/ ORBITER INTERFACES	(1HR)
D. REMOVE PROPELLANT TANK	(2HR)
E. RETURN PROPELLANT TANK TO RECEIVING AREA	(1HR)
F. PERFORM PROPELLANT TANK INSPECTION	(1HR)
G. PERFORM PROPELLANT TANK POST-FLIGHT CHECKOUT	(2HR)
H. PERFORM PROPELLANT TANK SERVICING, REPAIR, & MODIFICATION	(12HR)
I. PREPARE PROPELLANT TANK FOR NEXT FLIGHT	(4HR)
8. ORBITER PREPARATION	(2HR)
A. PERFORM ORBITER INSPECTION	(6HR)
B. PERFORM ORBITER POSTFLIGHT CHECKOUT	(16HR)
C. PERFORM ORBITER SERVICING, REPAIR, & MODIFICATION	(4HR)
9. SECURE ORBITER FROM HANGAR OPERATIONS	
10. PREPARE ORBITER FOR NEXT FLIGHT	

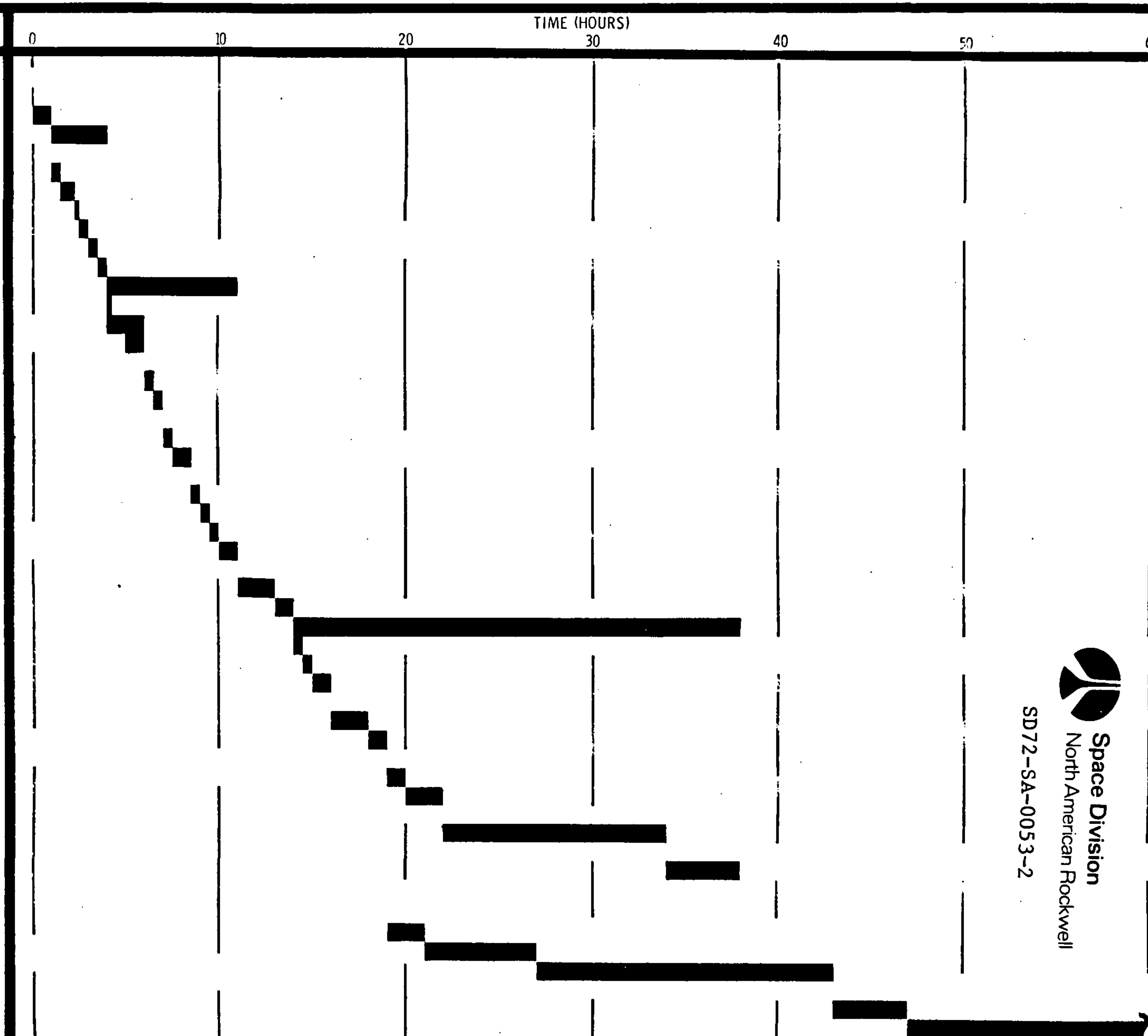

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Figure 9.4.1-2 Post-Flight Ground Operation Sequence

e. The space shuttle mobile launcher will be transported by the transporter from the VAB to the launch pad. The pad will have been previously prepared for the arrival of the shuttle system.

f. Start of 5-hour countdown will be initiated.

g. The liquid hydrogen and oxygen tanks will be preconditioned for initiation of propellant loading operations.

h. The launch pad will be cleared of all personnel, and rigid pad and vehicle access controls will be in effect.

i. Propellant loading of all tanks will be initiated. Chilldown of all transfer lines and tankage, venting, transfer, replenishment, and termination are accomplished by an automated system. After chilldown, simultaneous loading of all liquid oxygen and hydrogen into the booster, orbiter, and payload (if required) will begin. The logistics module loading will be initiated at the same time; however, liquid oxygen loading will precede liquid hydrogen loading in a series loading mode.

j. Next, the reactant tanks will be loaded and pressurized, and the fuel cells started.

k. The topping mode (low flow rate) of the propellant loading control system will be used to replenish propellants lost in boiloff.

l. Next, the terminal countdown which includes a verification that all systems are configured for launch will be performed.

m. During the final ten minutes prior to launch, the countdown will progress automatically.

n. The space shuttle will achieve a free liftoff and rise from the pad. The umbilicals will be retracted prior to liftoff, and the logistics module will then be supported by the orbiter systems.

Figure 9.4.1-2 presents the shuttle orbiter and logistics module post-flight ground operations (event, sequence, and time line) for vehicle landing and safing, and will consist primarily of the following:

a. The orbiter completes its mission and returns to the launch landing site and lands. The flight crew immediately initiates on-board safing, securing, and shutdown procedures.

b. The orbiter will be towed (or taxied) to the safing area.

c. Upon reaching the safing area, ground servicing system hookup and installation will begin concurrently with flight crew and passenger egress. At the same time, the pilot log and recorded flight data will be obtained and post-flight data analysis initiated.

d. During post-flight safing, the orbiter and logistics module liquid propellant residuals will be drained and propellant and reactant tanks will be vented and inerted. The vehicle interstitial spaces will be purged to remove heat from the structure; and all ordnance will be safed or removed.

e. When the safing and cooldown requirements have been met, the vehicle will be towed to the maintenance area for hangar operations.

f. Upon arrival at the maintenance hangar, the orbiter will be positioned, secured, placed on jacks, raised and leveled. Normal servicing will then commence as well as additional data analysis on any mission anomalies.

g. The orbiter will then be prepared for logistics module removal. First, the cargo bay doors will be opened and the cargo hoisting mechanism moved into place. Next, all logistics module/orbiter interfaces will be disconnected and the logistics module removed from the cargo bay. The logistics module will then be returned to the receiving area where a comprehensive inspection will be performed. Next, the logistics module will undergo a checkout in order to verify the post-flight integrity of all systems. Following checkout, the logistics module will undergo normal servicing and repair and modifications required prior to the next flight.

9.4.2 Orbiter Delivery and Fleet Sizing

The operational concept selected for delivery of propellants to orbit for use by the space-based tug, CIS, or RNS involves the use of a propellant module transported within the cargo bay of the shuttle. Individual mission payloads may accompany the propellant module inside the cargo bay whenever a full load of propellants is not planned. Since the average science payload for placement by the SB-tug weighs about 1500 pounds it can usually be accommodated on the shuttle by off-loading propellants from the propellant module. Usually, for CIS or RNS, the payloads are large and heavy and separate shuttle flights are scheduled for each.

For the CIS, operating in Mode 1, 19 shuttle flights are required to accomplish propellant loading for a lunar mission. Additional shuttle flights are required for CIS payload delivery and orbital maintenance. For the smaller, all hydrogen RNS, 10 shuttle flights are required for propellant logistics. These flights include allowance for boiloff and transfer losses. Some of the planetary missions in the program models such as Missions 51, 59, and 60 require two SB-tugs to insert the science payload and its propulsion package into the correct trajectory and permit return of both tugs to earth orbit and their subsequent reuse.

Typical mission profiles for these three types of payload placements are given in Figures 9.4.2-1 through 9.4.2-3. The full or near-full propellant tank and the mission science payload are boosted to the orbit of the user vehicle by the reusable space shuttle. The launch is planned from KSC for payload orbit inclinations between zero and 55 degrees and from Vandenberg Air Force Base for higher inclinations. Orbital parameters for the SB-tug are 180 n mi altitude and 28.5 degrees inclination; for the CIS or RNS the parameters are 180 n mi and 37.6 degrees.

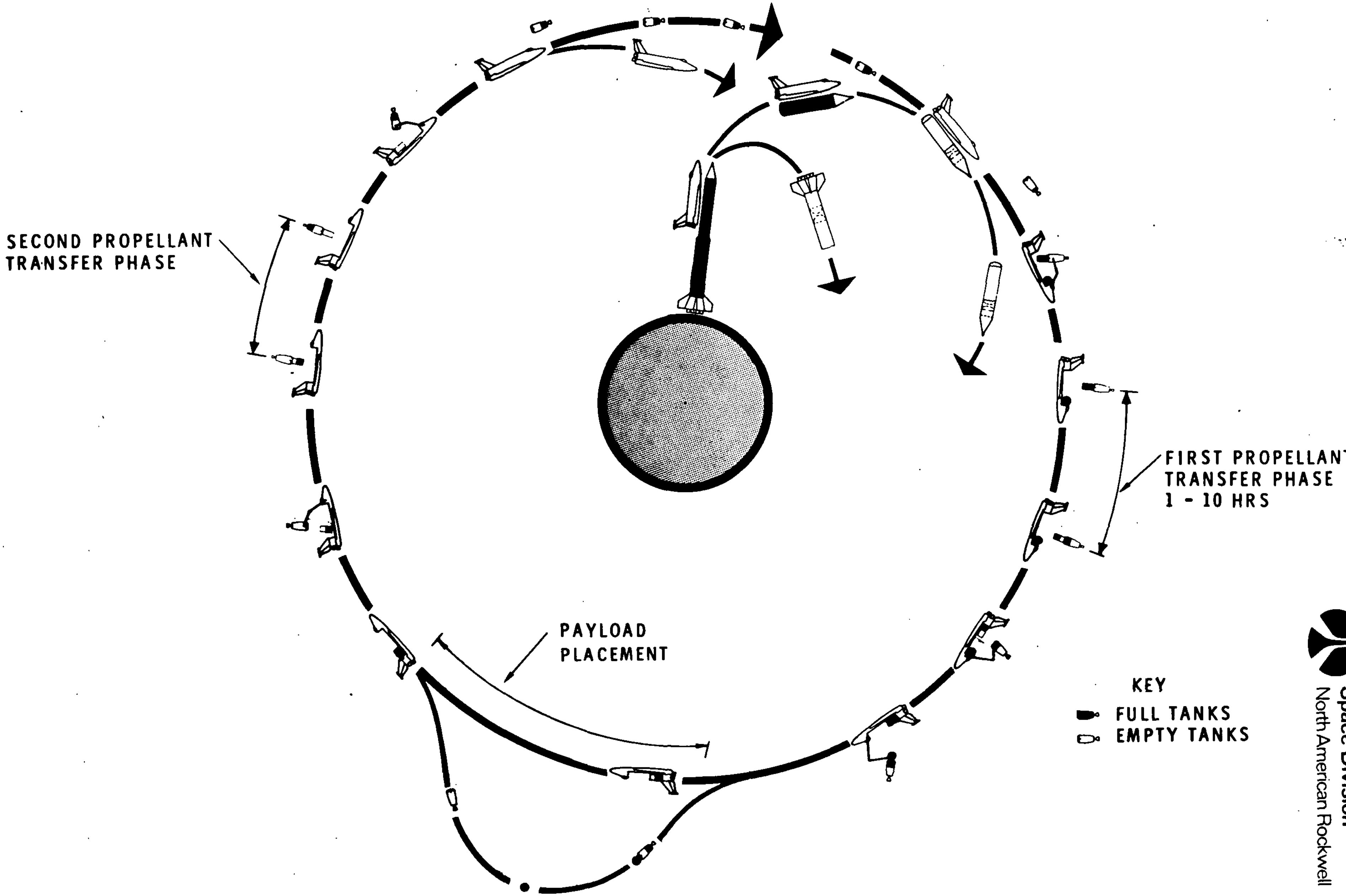

Figure 9.4.2-1 Space-Based Tug Propellant Logistics Mission Profile

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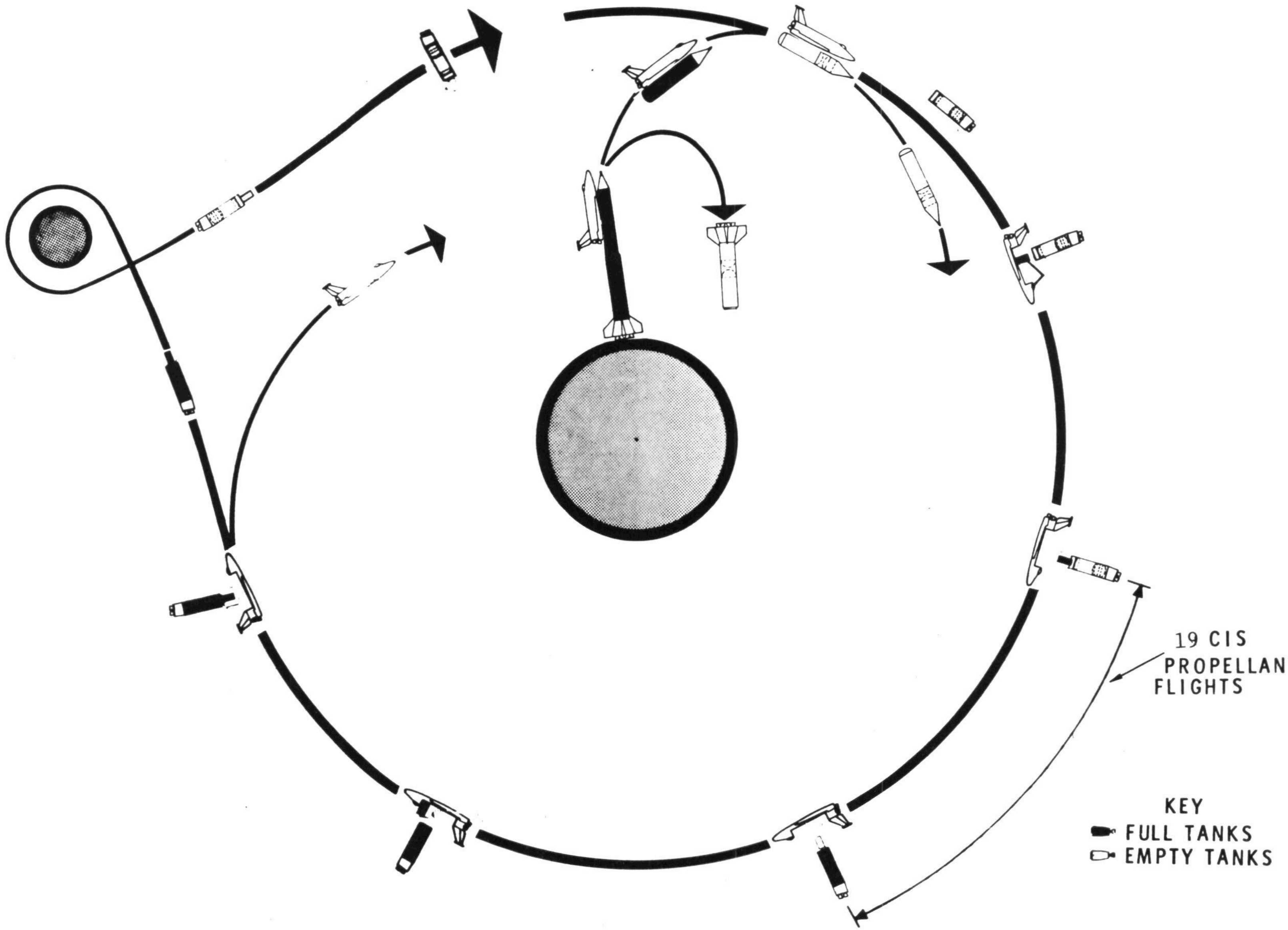

Figure 9.4.2-2 CIS Propellant Logistics Mission Profile

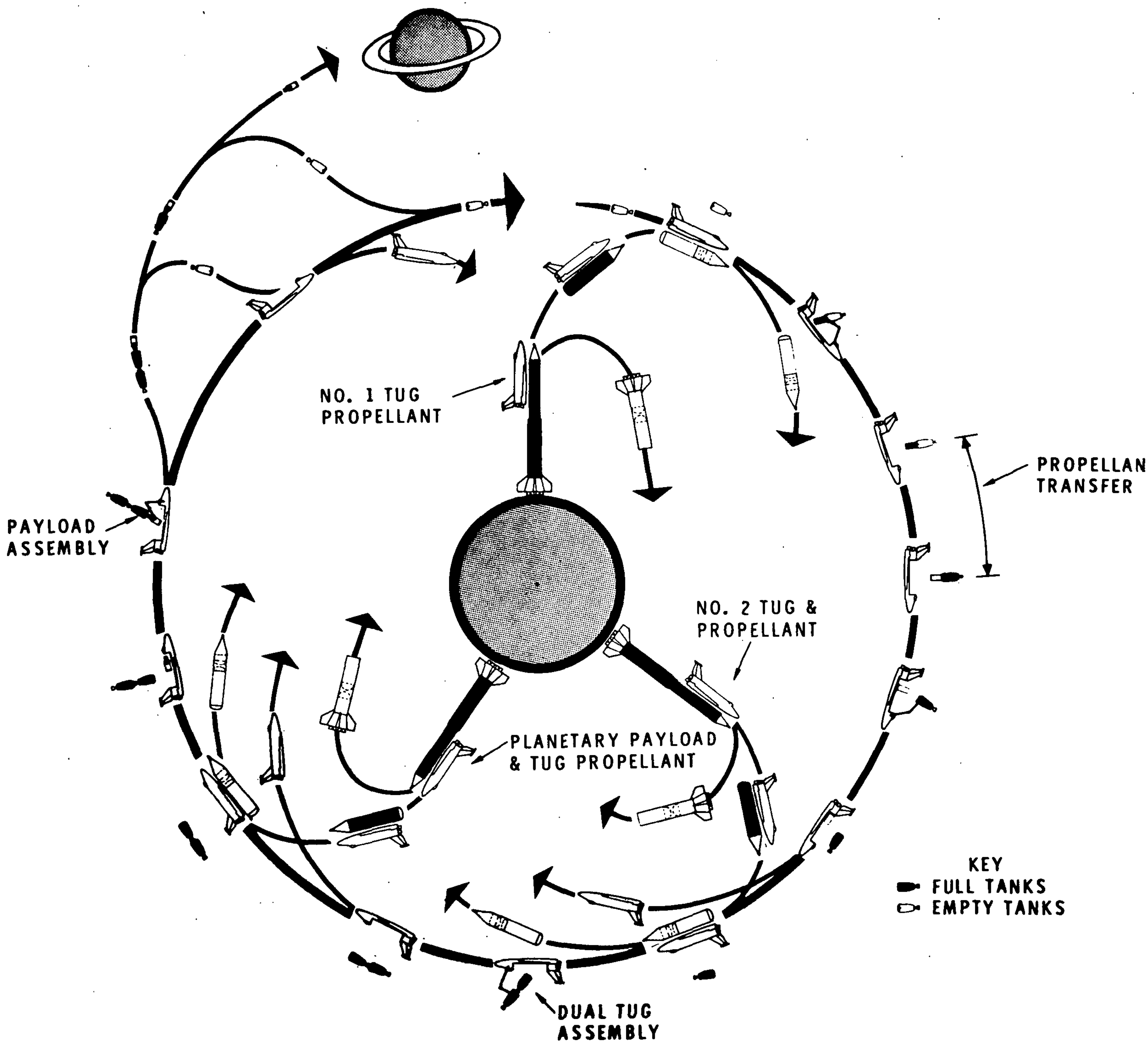

Figure 9.4.2-3 Dual Space-Based Tug Planetary Mission Profile

SEQUENCE OF EVENTS	DURATION
1. SHUTTLE LIFTOFF (T=0 SEC.) WITH LOGISTIC MODULE (LM) - PAYLOAD.	
2. BOOSTER STAGING (T≈141 SEC.)	
3. ORBITER INSERTION, 50 X 100 NMI ORBIT (T≈504 SEC.) AND COAST	1 HR:36 MIN
4. ORBITER TRANSFER ORBIT INSERTION (TOI) TO 180 NMI ORBIT	15 MIN
5. ORBITER COELLIPTIC ORBIT INSERTION (COI) 180 X 180 NMI ORBIT	15 MIN
6. ORBITER PERFORMS TERMINAL PHASE INITIATION (TPI) BURN FOR RENDEZVOUS WITH SB TUG	30 MIN
7. TERMINAL PHASE FINALIZATION (TPF) BRAKING BURN PERFORMED BY ORBITER FOR RENDEZVOUS WITH SB TUG (WITHIN REACH OF MANIPULATOR ARMS)	15 MIN
8. CARGO BAY DOORS OPENED	5 MIN
9. LOGISTIC MODULE ROTATED AND SUPPORTED BY SWING-OUT RING	5 MIN
10. MANIPULATOR ARM GRASPS TUG, TUG DRAWN TO DOCKING WITH LM	15 MIN
11. LM/SB TUG EXTEND RACK AND ENGAGE INDEX PROBE	5 MIN
12. LM/SB TUG ELECTRICAL CONNECTORS ENGAGED	5 MIN
13. LM/SB TUG PROPELLANT TRANSFER AND GAS RETURN LINES ENGAGED	5 MIN
14. LM/SB TUG PERFORM PRE-TRANSFER CHECKOUT	40 MIN
15. LM DETACHED FROM SWING-OUT RING USING MANIPULATOR ARM	10 MIN
16. LM/SB TUG MOVED AWAY FROM ORBITER BY MANIPULATOR ARM	10 MIN
17. ARMS RELEASE LM/SB TUG	5 MIN
18. ORBITER MOVES A SAFE DISTANCE (≈5 NMI) AWAY FROM LM/SB TUG	2 HRS.
19. PROPELLANT TRANSFER TO SB TUG (PERIOD OF THRUSTING)	9 HRS.
A. PROPELLANT SETTLING (LINEAR ACCELERATION)	30 MIN
B. PRESSURIZATION AND CHILLING	30 MIN
C. FAST FILL, SB TUG	6 HRS.
D. THROTTLED FILL TO MISSION REQUIREMENTS	1 HR:20 MIN
E. LIQUID DRAIN: LT/SB TUG TRANSFER LINES	30 MIN
F. DEPRESSURIZATION	10 MIN
G. TERMINATE LINEAR ACCELERATION	—
20. POST TRANSFER CHECKOUT AND SECURING	1 HR
21. LM/SB TUG RENDEZVOUS WITH ORBITER (WITHIN REACH OF MANIPULATOR ARMS)	30 MIN
22. CARGO BAY DOORS OPENED	5 MIN
23. MANIPULATOR ARM GRASPS LM/SB TUG. LM DRAWN TO DOCKING WITH ORBITER SWING-OUT RING	15 MIN
24. LM/ORBITER EXTEND INTERFACE RACK AND ENGAGE INDEX PROBE	5 MIN
25. LM/ORBITER ELECTRICAL AND REMATIBLE INSULATION PRESSURIZATION LINE ENGAGED	5 MIN
26. LM/SB TUG PROPELLANT TRANSFER AND GAS RETURN LINES RETRACTED	5 MIN
27. LM/SB TUG ELECTRICAL CONNECTORS DISENGAGED	5 MIN
28. LOGISTIC MODULE DOCKING FIXTURE RELEASES SB TUG	5 MIN
29. MANIPULATOR ARM MOVES SB TUG AWAY FROM LM	10 MIN
30. LOGISTIC MODULE (WITH REMAINING PROPELLANT) RETURNED TO AND SECURED IN CARGO BAY AND ALL REMAINING REMATIBLE SYSTEM LINES ENGAGED.	15 MIN
31. ORBITER DEPLOYS PAYLOAD AND HARD DOCKS PAYLOAD TO SB TUG USING MANIPULATOR ARMS	30 MIN
32. CARGO BAY DOORS CLOSED	5 MIN
33. SB TUG DELIVERS PAYLOAD TO DESIRED ORBIT AND RETURNS TO 180 X 180 NMI ORBIT (DURING THIS PERIOD OF TIME THE ORBITER COULD HAVE PERFORMED ANOTHER MISSION)	18 HRS:30 MIN

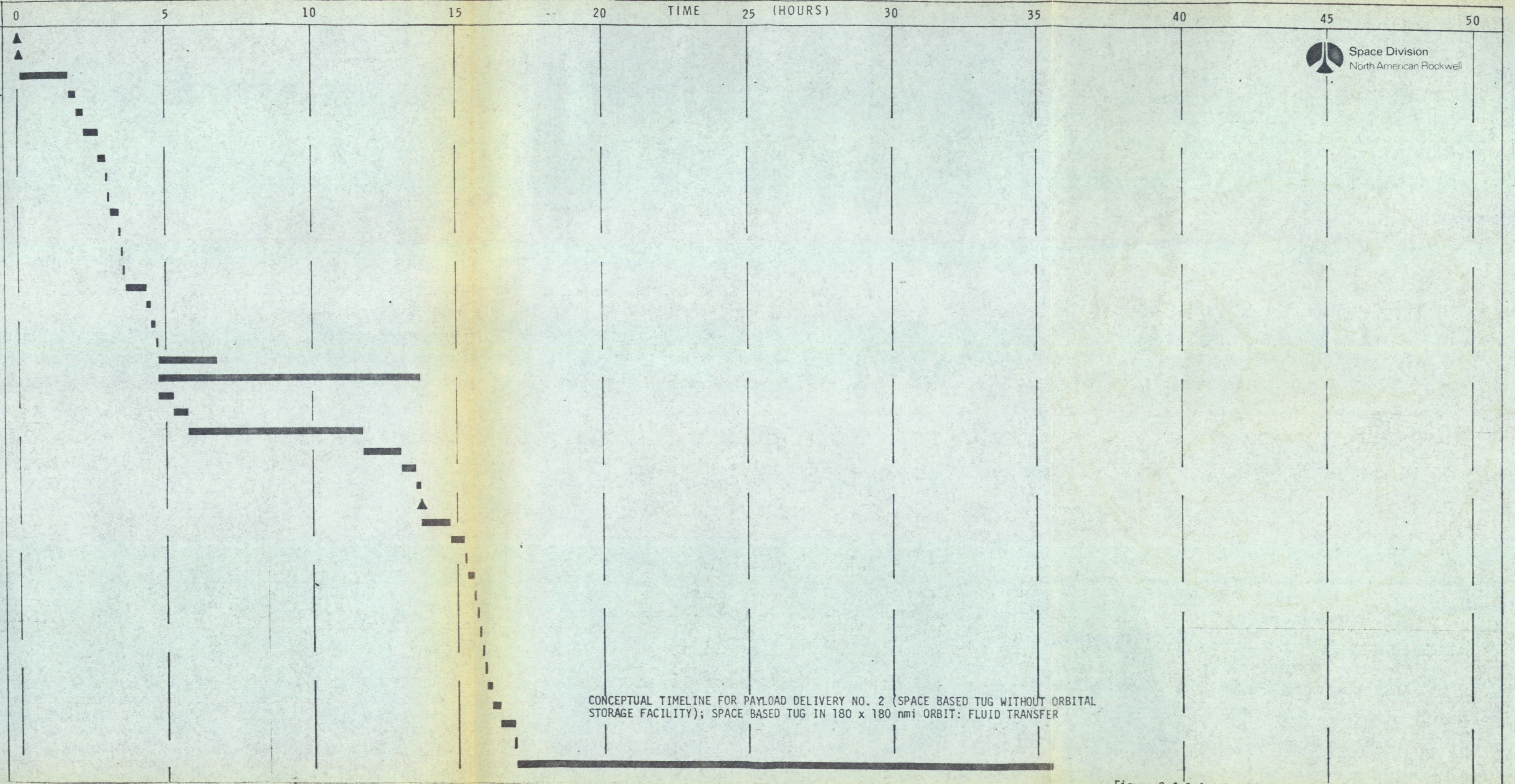

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Figure 9.4.2-4a In Flight Operation Sequence

SEQUENCE OF EVENTS	DURATION
34. TERMINAL PHASE FINALIZATION (TPF) BRAKING BURN PERFORMED BY ORBITER FOR RENDEZVOUS WITH SB TUG (WITHIN REACH OF MANIPULATOR ARMS)	15 MIN
35. CARGO BAY DOORS OPENED	5 MIN
36. LOGISTIC MODULE ROTATED AND SUPPORTED BY SWING-OUT RING	5 MIN
37. MANIPULATOR ARM GRASPS TUG, TUG DRAWN TO DOCKING WITH LM	15 MIN
38. LM/SB TUG EXTEND RACK AND ENGAGE INDEX PROBE	5 MIN
39. LM/SB TUG ELECTRICAL CONNECTORS ENGAGED	5 MIN
40. LM/SB TUG PROPELLANT TRANSFER AND GAS RETURN LINES ENGAGED	5 MIN
41. LM/SB TUG PERFORM PRE-TRANSFER CHECKOUT	40 MIN
42. LM DETACHED FROM SWING-OUT RING USING MANIPULATOR ARM	10 MIN
43. LM/SB TUG MOVED AWAY FROM ORBITER BY MANIPULATOR ARM	10 MIN
44. ARMS RELEASE LM/SB TUG	5 MIN
45. ORBITER MOVES A SAFE DISTANCE (≈5 NMI) AWAY FROM LM/SB TUG	2 HRS.
46. PROPELLANT TRANSFER TO SB TUG (PERIOD OF THRUSTING)	4 HRS:30 MIN
A. PROPELLANT SETTLING (LINEAR ACCELERATION)	30 MIN
B. PRESSURIZATION AND CHILLING	30 MIN
C. FAST FILL, SB TUG	1 HR
D. THROTTLED FILL TO ORBITAL MAKEUP AND STORAGE PROPELLANT REQUIREMENTS	1 HR:50 MIN
E. LIQUID DRAIN: LT/SB TUG TRANSFER LINES	30 MIN
F. DEPRESSURIZATION	10 MIN
G. TERMINATE LINEAR ACCELERATION	
47. POST TRANSFER CHECKOUT AND SECURING	1 HR
48. LM/SB TUG RENDEZVOUS WITH ORBITER (WITHIN REACH OF MANIPULATOR ARMS)	30 MIN
49. CARGO BAY DOORS OPENED	5 MIN
50. MANIPULATOR ARM GRASPS LM/SB TUG. LM DRAWN TO DOCKING WITH ORBITER SWING-OUT RING	15 MIN
51. LM/ORBITER EXTEND INTERFACE RACK AND ENGAGE INDEX PROBE	5 MIN
52. LM/ORBITER ELECTRICAL AND REMATIBLE INSULATION PRESSURIZATION LINE ENGAGED	5 MIN
53. LM/SB TUG PROPELLANT TRANSFER AND GAS RETURN LINES RETRACTED	5 MIN
54. LM/SB TUG ELECTRICAL CONNECTORS DISENGAGED	5 MIN
55. LOGISTIC MODULE DOCKING FIXTURE RELEASES SB TUG	5 MIN
56. MANIPULATOR ARM MOVES SB TUG AWAY FROM LM	10 MIN
57. EMPTY LOGISTIC MODULE RETURNED TO AND SECURED IN CARGO BAY AND ALL REMAINING REMATIBLE SYSTEM LINES ENGAGED.	15 MIN
58. CARGO BAY DOORS CLOSED	5 MIN
59. ORBITER DE-ORBITS AND LANDS WITH EMPTY LOGISTIC MODULE	1 HR:30 MIN
60. SB TUG REMAINS IN 180 X 180 NMI ORBIT UNTIL NEXT MISSION	—

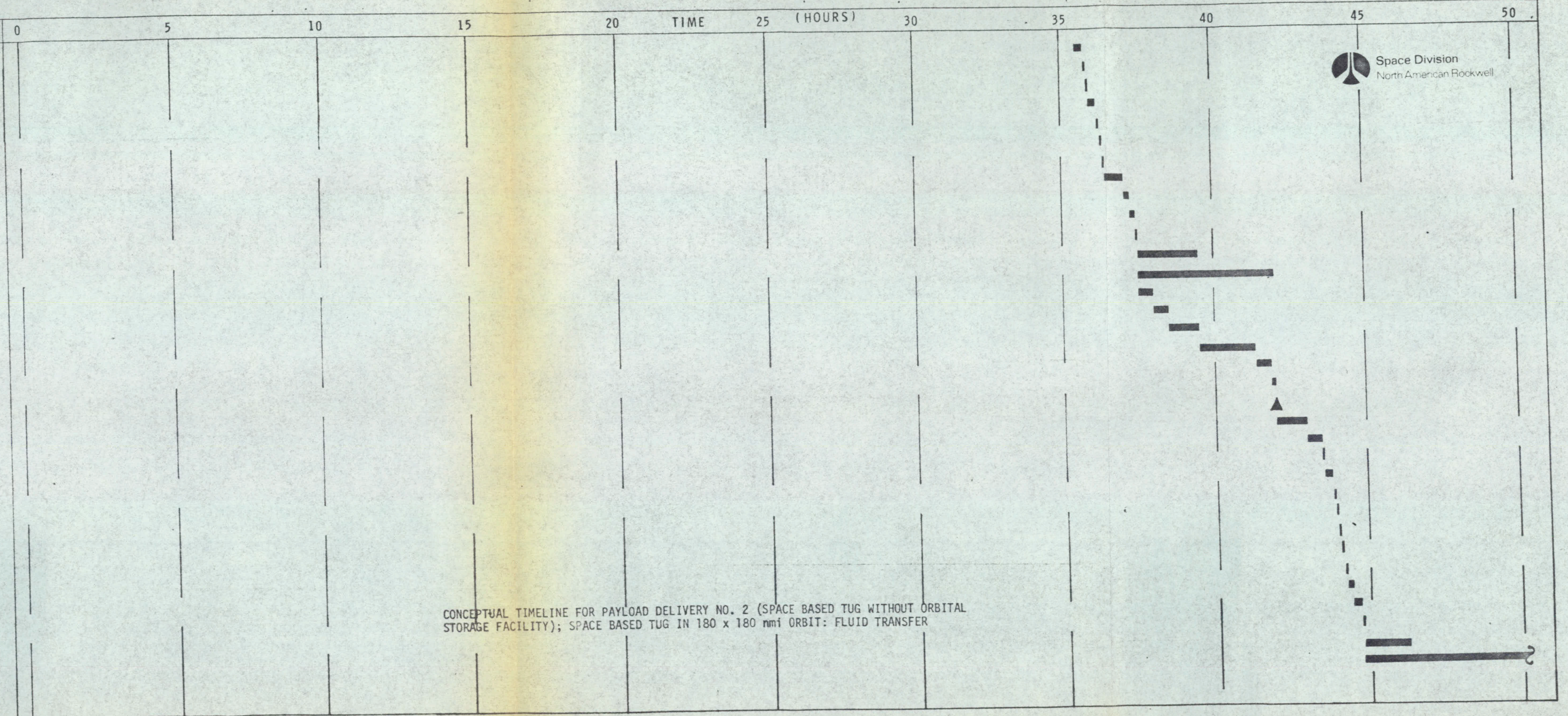

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Figure 9.4.2-4 b In-Flight Operation Sequence

A typical propellant logistics mission to the SB-tug is timelined in Figure 9.4.2-4. An overall duration of 47 hours is shown. This is a relatively short mission; average mission duration is about 5.7 days based on all the missions in Program Level C. The longer duration is due to increased placement time by the tug. The timeline sequence covers the major mission phases of ascent, propellant transfer, orbit hold during science payload placement by SB-tug, transfer of remaining propellant to SB-tug, and descent.

An analysis of SB-tug, propellant module, and space shuttle fleet size and the number of launch pads required to support the various program levels is summarized in Figures 9.4.2-5 through -8. These plots show the effect of program element flight rate on the number of program elements required to support the placement missions for various mission durations. Utilizing these plots and the data summarized in Table 9.4.2-1, which presents the number of flights required to support propellant logistics missions for the space-based tug, the fleet size and utilization rates for these specific flights were determined. The results are given in Table 9.4.2-2. They are based on the flights of Table 9.4.2-1 being equally spaced and therefore do not include the effects of non-equal spacing such as occurs during CIS refueling and dual-tug missions.

Table 9.4.2-1. Propellant Logistics Flight Summary

Program Level	Space Shuttle Flights (1)	SB-Tug Flights	SB-Tug Payload Placements
A	0	0	0
B	139	122	117
C	184	163	157
D	727	443	429
E	789	436	424

(1) In support of space-based tug and based on CIS and Tug Concept 2.

An important factor in sizing the fleet is the mission duration which is defined here as the sum of flight time and ground turnaround time. No time was included for downtime in the mission durations of Table 9.4.2-2, but these can be added directly on a day-for-day basis and the corresponding fleet size can be obtained from Figures 9.4.2-5 through -8 as before since the parametric mission durations on the plots are for any combination of calendar days.

The mission durations selected were based on a calculated average mission flight time for the SB-tug over all the missions of Program Level C. This assumes an average duration of eight days for long duration, geosynchronous missions which includes two days for ascent, rendezvous and propellant transfer; one day for orbital phasing and ascent; two days for payload deployment, thermal stabilization, outgassing, and checkout; one day for phasing, descent, and rendezvous with the orbiter; one day for propellant transfer; and one day for landing site phasing, descent, and landing. In Program C there are 206 such missions and 127 short duration missions which require two days each. The average flight duration is therefore 5.7 days.

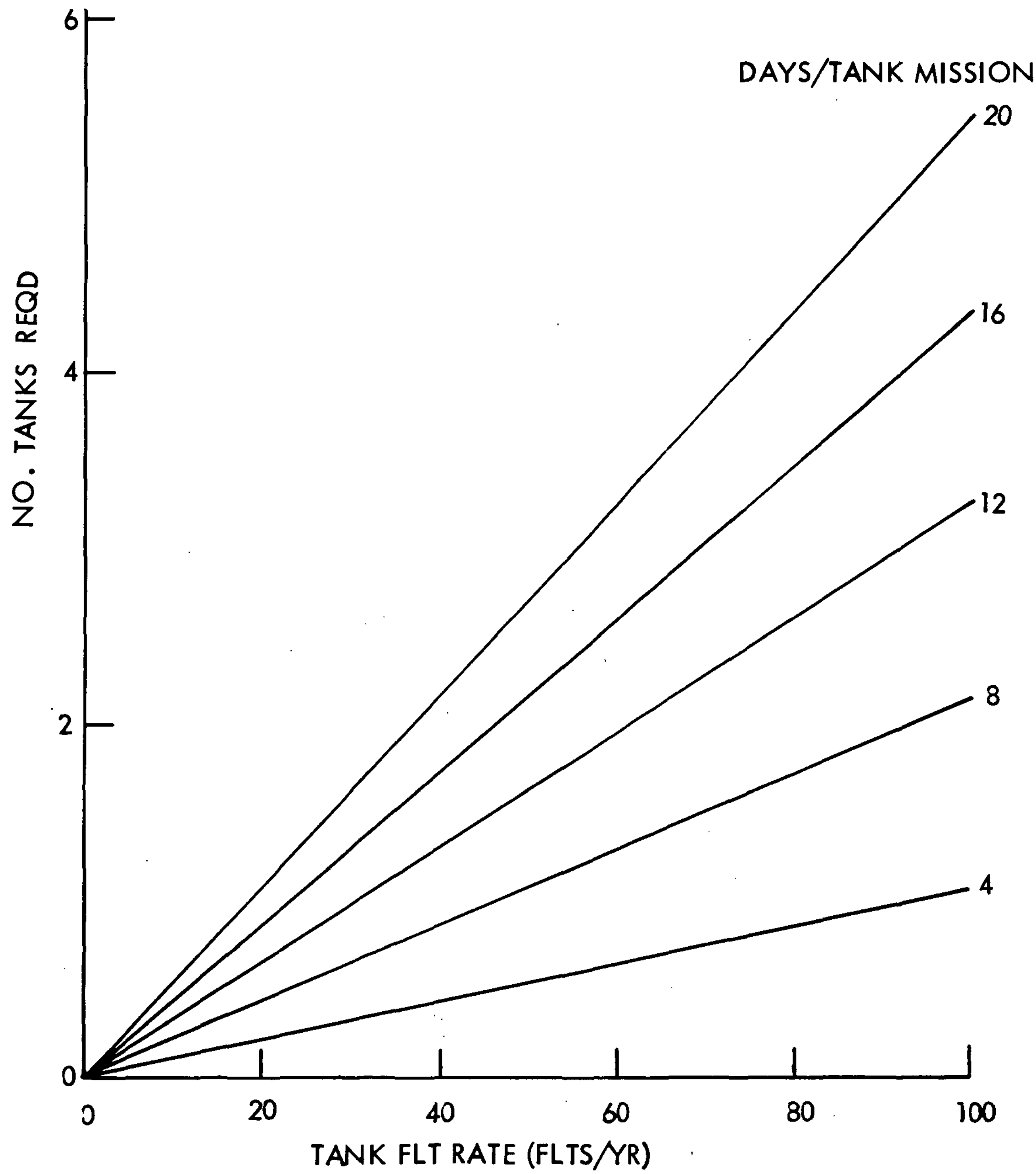


Figure 9.4.2-5 Effect of Tank Mission Duration on Tank Fleet Size

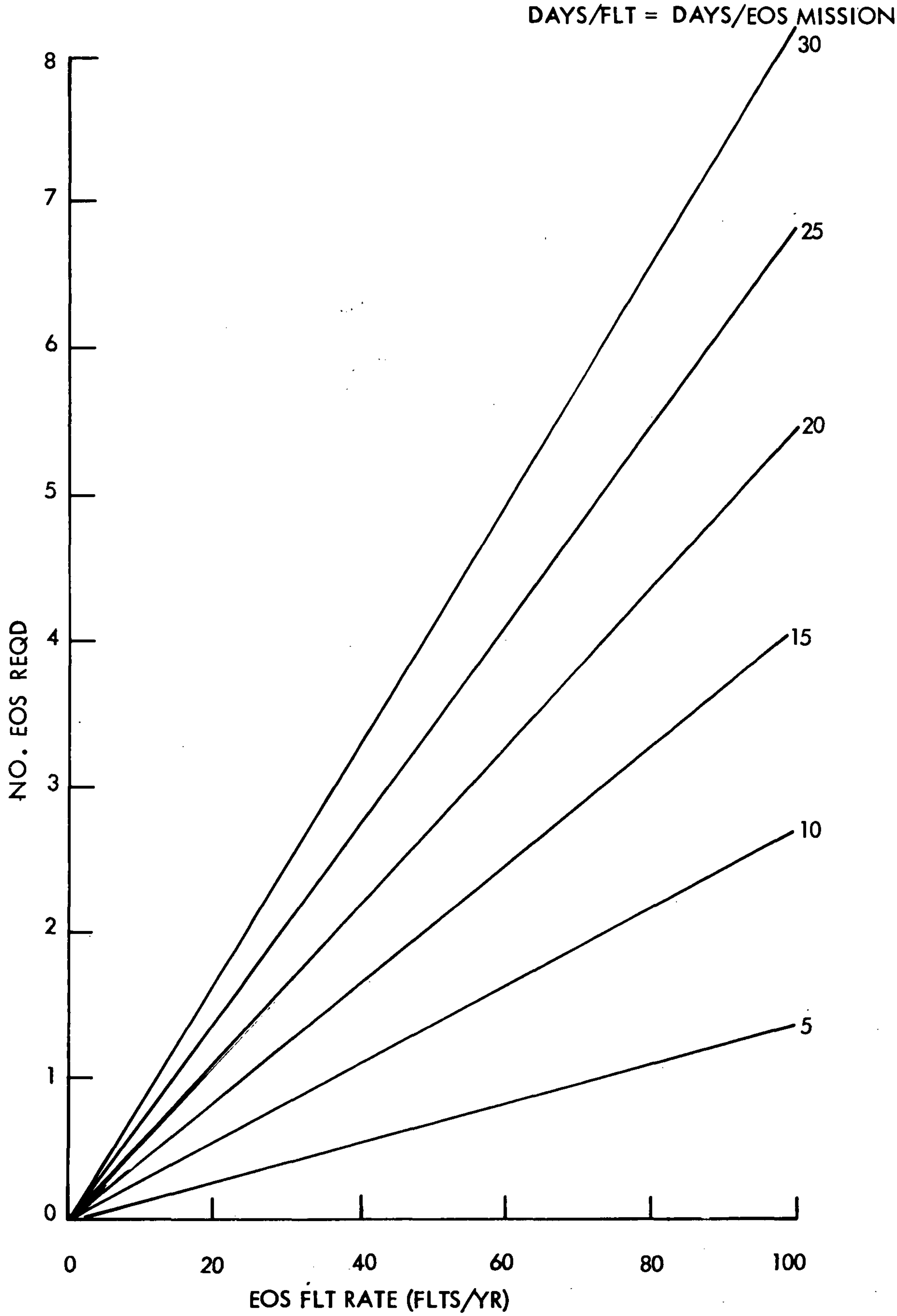


Figure 9.4.2-6 Effect of Orbital Mission Duration on Shuttle Fleet Size

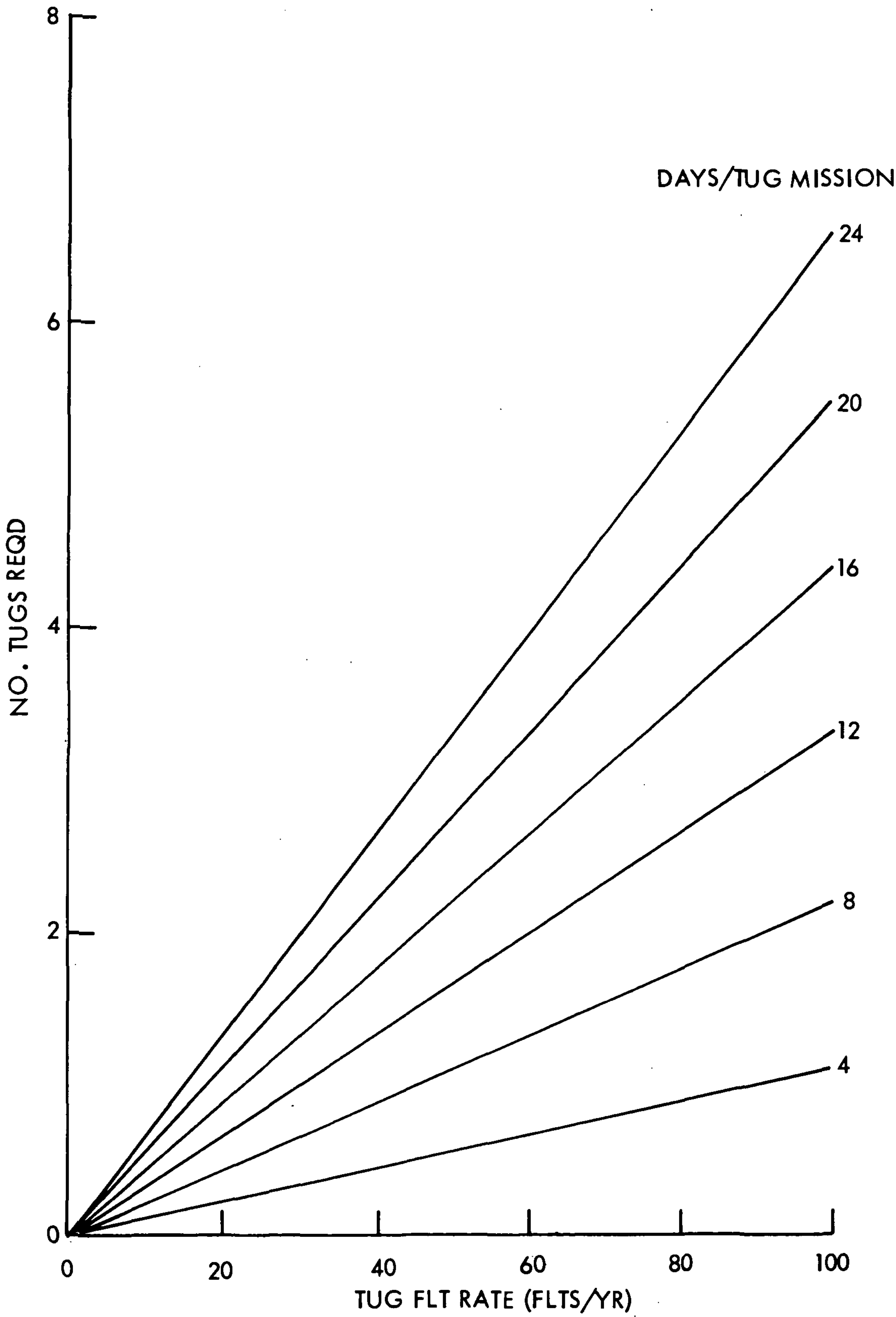


Figure 9.4.2-7 Effect of Tug Mission Duration on Tug Fleet Size

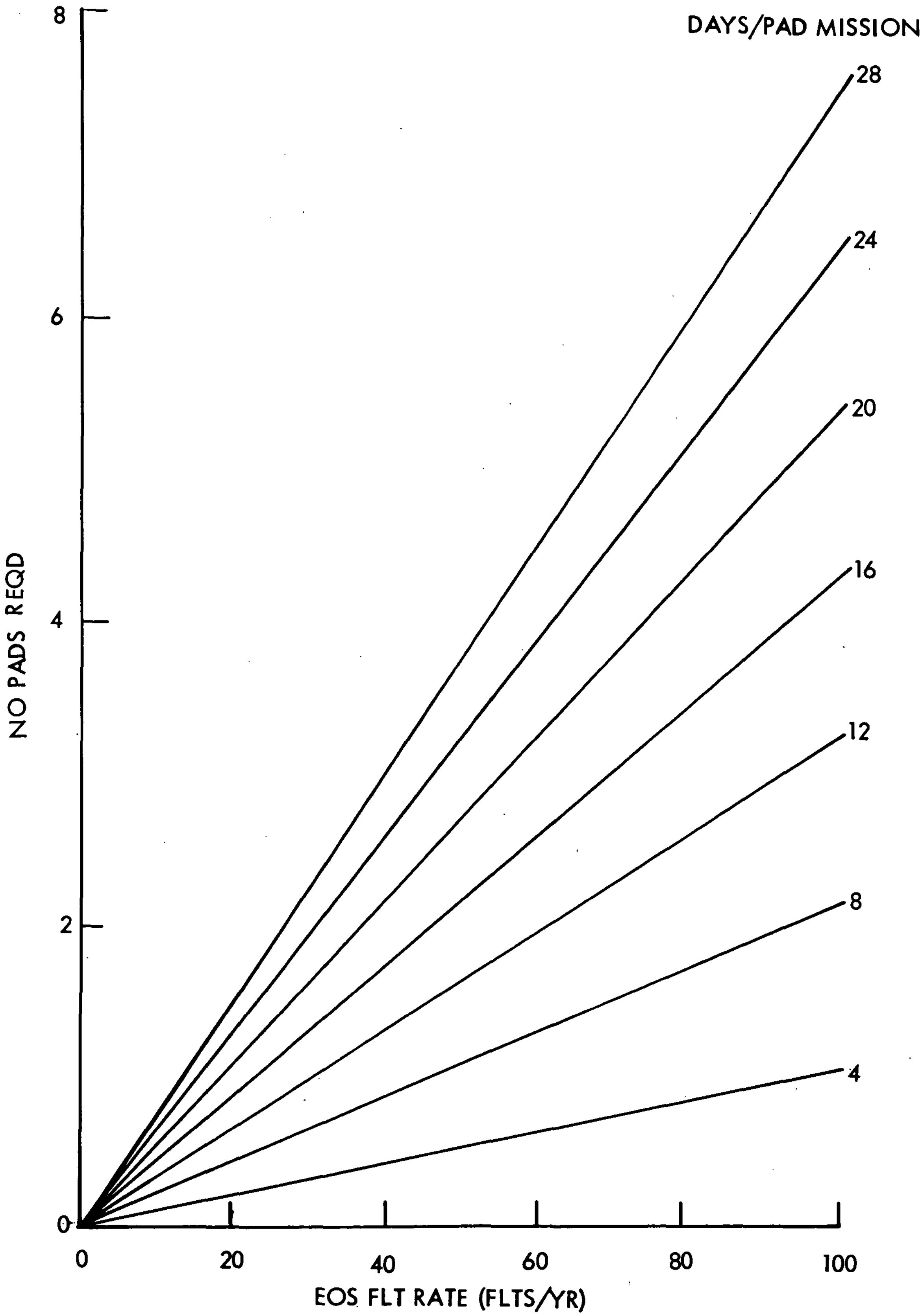


Figure 9.4.2-8 Effect of Pad Turnaround Time on Number of Launch Pads Required

Table 9.4.2-2. Fleet Size and Utilization Summary

Program Elements	Program Level				
	A	B	C	D	E
Propellant Modules					
Mission duration (days)	0	9.7	9.7	9.7	9.7
No. PM's required	0	1	1	2	2
PM life required (missions)	0	139	184	364	394
Flight rate (missions/year)	0	23.2	30.6	60.5	65.6
Mission interval (days/mission)	0	15.8	11.9	6.1	5.6
Space Shuttle					
Mission duration	0	19.7	19.7	19.7	19.7
No. shuttles required	0	2	2	4	4
Shuttle life required	0	139	184	182	197
Flight rate	0	23.2	30.6	60.5	65.6
Mission interval	0	15.8	11.9	6.1	5.6
SB-Tugs					
Mission duration	0	9.7	9.7	9.7	9.7
No. tugs required*	0	1	1	1	1
Tug life required	0	122	163	226	225
Flight rate	0	20.4	27.2	37.7	37.6
Mission interval	0	17.9	13.4	9.7	9.7
Launch Pads					
Launch cycle duration	0	12.0	12.0	12.0	12.0
No. pads required	0	1	2	2	3
Pad life required (launches)	0	139	184	364	263
Flight rate	0	23.2	30.6	60.5	65.6
Launch interval	0	15.8	11.9	6.1	5.6

*For the three planetary missions with dual tugs, one additional tug is required.

The ground turnaround time for the SB-tug is based on a return to earth after each 10 missions for Level II-type refurbishment of critical components such as fuel cells and, after every 50 missions, for Level III maintenance including engine replacement and major repairs. Level II maintenance is estimated at 10 days duration and Level III at 30 days. The average ground turnaround time per mission then is four days so that the average SB-tug mission duration is 9.7 days.

The shuttle (orbiter) mission duration is based on the tug flight duration because the orbiter waits on station for the tug to return for the second propellant filling operation (Concept 2). Therefore, the shuttle mission duration is 5.7 days plus the orbiter ground turnaround time of 14 days for a total of 19.7 days.

Similarly, the logistics tank mission duration is 5.7 days for flight operations and four days for ground turnaround, or 9.7 days.

The launch pad cycle is based on a two-day shuttle installation and countdown and a 10-day refurbishment for a 12-day total. All of these assumed mission durations were used to establish the fleet size and the number of launch pads required for support to propellant logistics missions.

The results show a surprisingly small fleet of program elements necessary to support SB-tug operations at the various program levels. Note that there are no space-based tug flights for Program Level A and that Program Levels B and C only utilize the SB-tug in the 1985 through 1990 period, while D and E utilize the SB-tug for all 12 years. Peak, rather than average, launch rates would require a somewhat larger fleet size.
To obtain the required total production quantities of propellant modules to permit estimation of program costs, three categories of propellant module utilization have been established. They are propellant modules used for flight operations, propellant modules in flight readiness for use as immediate backup in the event ground maintenance cannot be completed in time for a scheduled launch, and propellant modules in storage as spares.

The number of propellant modules required for flight operations is based on the number of shuttles required for propellant logistics operations as given in Table 9.4.2-2 and the programming requirement of assignment of a specific propellant module to each shuttle. Thus propellant modules are assigned on the basis of one module for one shuttle and not as given in the table for propellant module fleet size. This is to permit optimizing each module and its orbiter rather than relying on interchangeability and 100 percent utilization (no downtime) of modules to minimize their production quantities. The estimated production quantities for each of these categories are given in Table 9.4.2-3 for each program level. Unlike the averaged quantities of program elements identified in Table 9.4.2-2, these flight operation requirements are based on peak logistics mission launch rates per year. The peak rates were used because they represent the maximum number of simultaneously required shuttles and propellant modules and therefore the quantity which must be built. The peak launch rates and the year of their occurrence are: Program Level B - 27 in 1987; Program Level C - 35 in 1985; Program Level D - 89 in 1989; and Program Level E - 102 in 1987.

Table 9.4.2-3. Propellant Module Production Quantities

Use Category	Program Level				
	A	B	C	D	E
Flight operations (one/orbiter)	0	2	2	5	6
Downtime backup (50 percent)	0	1	1	1	1
Spares	0	1	1	1	1
Total	0	4	4	7	8

9.4.3 Deployment and Docking

The deployment and docking concept is summarized in Figure 9.4.3-1. The sequence numbers are an expansion of the time line entries of Figure 9.4.2-4. The illustrations show the docking of a tug, but since the deployment and docking operations are essentially the same for any user vehicle, the description will be in general terms.

The propellant module deployment sequence begins with the orbiter in close proximity and stationkeeping with the stabilized user vehicle. The orbiter cargo bay doors are open and the manipulator arms have moved with the doors and are out of the way of the cargo. Both the propellant module and the user will be checked out to verify that docking and propellant transfer systems are functioning. The hinge pins for the deployment ring are engaged, followed by the uncoupling of the cargo bay line interconnects. (The electrical connections to the module are not yet broken.) These operations are verified and the deployment ring attachment to the module is checked. Then the orbiter cargo retention fittings release the module. A manipulator arm may be deployed with floodlight and TV to provide visual monitoring by the orbiter crew. Next, the deployment ring is actuated to rotate the module out of the cargo bay. Rotation is 30° to 40°. The deployment ring is stabilized in this position by its actuating mechanism and/or support struts.

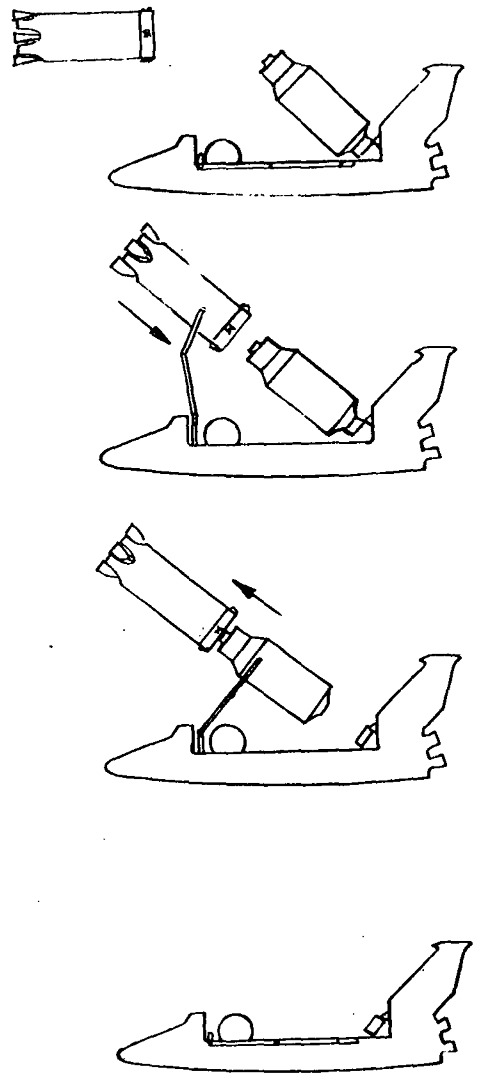
A manipulator arm is then deployed and attaches to the user vehicle. The user vehicle active docking fixture system is activated as necessary. Under manipulator arm control the user vehicle is aligned and brought to a "soft" docking (or berthing) with the propellant module. The docking fixture draws the modules to their final position and the attach latches are engaged. With docking verified, the interconnect covers can be deployed and the transfer line interconnects made and checked. Control of the propellant module is then assumed by the user vehicle. After verification of user power supply and monitoring and control of the module, the orbiter electrical connections are disengaged. The module is released from the deployment ring and moved away from the orbiter. The initial movement of module and user can be accomplished by the manipulator arm. If this is preferred over active withdrawal by the user, the manipulator arm may first need to shift from the user to attachment to the propellant module. This would be done just prior to module release from the deployment ring.

After the propellant transfer phase of the logistics operation, the module is returned to the cargo bay. This is essentially a reversal of the procedures outlined above. The orbiter would again rendezvous with the user and check out all necessary systems. The manipulator arm would attach to the logistics module and dock it to the deployed swing-out ring. Electrical connections would be remated to the orbiter and the orbiter would regain module control. With the module attached to and stabilized by the deployment ring, the manipulator arm could shift to the user. After disengagement of transfer line interconnects and docking attachment release, the user could be moved away from the module.

The module would then be returned to the cargo bay (by rotation of the deployment ring) and captured by the retention fittings. The cargo bay line inter-

SEQUENCE NUMBER (REFERENCE)

7 RENDEZVOUS WITHIN REACH OF MANIPULATOR ARMS
8 CARGO BAY DOORS OPENED
9 TANK MODULE ROTATED AND SUPPORTED BY SWING OUT RING
10 { MANIPULATOR ARM GRASPS TUG
TUG DRAWN TO DOCKING WITH TANK
15 TANK DETACHED FROM SUPPORT RING
16 TANK/TUG MOVED AWAY BY MANIPULATOR ARM
17 ARM RELEASES TANK/TUG
18 ORBITER MOVES TO SAFE DISTANCE
19 { TRANSFER INITIATED
TRANSFER COMPLETE
21 TANK/TUG RENDEZVOUS WITH ORBITER
WITHIN REACH OF MANIPULATOR ARMS
23 { ARM GRASPS TANK/TUG
TANK DRAWN TO SUPPORT RING
28 TANK DOCKING FIXTURE RELEASES TUG
29 MANIPULATOR ARM MOVES TUG AWAY FROM TANK MODULE



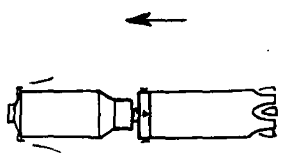


Figure 9.4.3-1 Docking and Deployment Operational Concept

connects would then be re-engaged for module venting (the insulation repressurization line was engaged along with the electrical connections). Last, the deployment ring hinge pins would be disengaged to allow the orbiter retention fittings to carry all module loads.

9.4.4 Propellant Transfer

The sequence of operations for the in-space propellant delivery concept is shown in Figure 9.4.2-4.

Time lines are given for the principal functions involved in transporting propellant from earth to a space-based tug using the space shuttle system. The sequence is given for the operations from launch to orbiter landing.

The following discussion will be directed to operations required for that portion of the mission dealing with the fluid transfer of the propellant from the logistics module to the space-based tug.

Operational Items 1 through 13 of Figure 9.4.2-4 give the sequence for placing the orbiter into a 180 x 180 nautical mile orbit, rendezvous with the tug, and docking the propellant module with the tug. At this time, a comprehensive transfer system and interface checkout (Item 14) will be conducted. The objective of this checkout will be to insure that the complete propellant transfer system comprised of the components of the logistic module and tug, together with the interface connections, is operable and safe. Checks will be made to detect leaks, measure the propellant conditions, and determine that the proper power and control signals are available for normal propellant transfer conditions. The attachment to the orbiter will be retained until the checkout has been completed and the system integrity has been established. At this time, the tug and logistic module will be separated from the deployment ring and extended by the manipulator arm (Item 16). Stationkeeping mode will be established by the tug guidance and control equipment and the tug and logistics module separated from the orbiter. At this time, a maneuver will be initiated (Item 18) to transfer the orbiter to the desired parking position (five miles separation). For this maneuver, the orbiter can be retrograded into a tangent elliptical phasing orbit and recircularized at the desired position in the initial orbit. After the orbiter transfer maneuver has been initiated and verified the propellant transfer operations (Item 19) will be initiated. Table 9.4.4-1 is a summary of the operations required for the propellant transfer phase of the mission. This table lists the control systems, sensors, and the expected LH_2 propellant conditions in the logistics module and tug for each operation.

The propellant liquid/vapor interface control will be established by the cross plane linear acceleration technique. For this operation the tug and logistic module will be oriented and maintained in an attitude with the longitudinal axis of the vehicles perpendicular to the initial orbital plane and then cross-plane linear thrusting will be initiated by actuating the thrusters on the logistic module. Thrusting will be continuous for the full duration of the propellant transfer phase of the mission and will be terminated at the first optimum orbital position following completion of the transfer operation.

Table 9.4.4-1 Propellant Transfer Operation

SEQUENCE NO (REFERENCE)	OPERATION	CONTROL	FEEDBACK SENSOR	PROPELLANT CONDITION (LH_2)	
				LOGISTIC TANK	TUG
14	PREPARATION & CHECKOUT	GROUND & ONBOARD CHECKOUT EQUIPMENT	TUG & TANK CHECKOUT SENSORS	0-G ENVIRONMENT 15-16 PSIA 37°R	0-G ENVIRONMENT 15-16 PSIA 37°R
19A	LINEAR ACCELERATION INITIATED	APS JETS ON	• PREPARATION & CHECKOUT COMPLETE • SHUTTLE AT SAFE DISTANCE	10^{-4} G 15-16 PSIA 37°R	10^{-4} G 15-16 PSIA 37°R
	VERIFY PROPELLANTS SETTLED		MASS & LEVEL SENSORS		
19B	PRESSURIZE	• PUMP & GAS GENERATOR ON/OFF • PRESSURANT FLOW REGULATION	ULLAGE PRESSURE MEASUREMENT	19 PSIA	19 PSIA
	LOW FLOW CHILL	• PUMP START UP • LOGISTIC TANK FLOW CONTROL VALVES	TANK & TUG LINE TEMPERATURES AND PRESSURES	100 LB/HR 21 PSIA	100 LB/HR 19 PSIA
19C	FAST FILL	FLOW CONTROL VALVES	• FLOW METERS • MASS & LEVEL SENSORS	1,000 LB/HR	1,000 LB/HR
19D	THROTTLED FLOW	FLOW CONTROL VALVES	• POINT SENSORS AT LOGISTIC TANK OUTLET	1,000 TO 100 LB/HR	1,000 TO 100 LB/HR
	TRANSFER TERMINATION	• PUMP SHUWDOWN • VALVE CLOSURE	• TUG LOADING ACHIEVED (1ST TRANSFER) • LOGISTIC TANK DRAINED (2ND TRANSFER)	19 PSIA 37°R	19 PSIA 37°R
19E	DRAIN LINES	VALVE CONTROL	TRANSFER LINE TEMPERATURE		
19F	DEPRESSURIZE	• PUMP & GAS GENERATOR OFF • VENT VALVES OPEN/CLOSE	ULLAGE PRESSURE MEASUREMENT	15 PSIA 37°R 10^{-4} G	15 PSIA 37°R 10^{-4} G
19G	LINEAR ACCELERATION TERMINATED	APS JETS OFF	• TUG & SHUTTLE AT	0 G	0 G
20	POST TRANSFER CHECKOUT	GROUND & ONBOARD CHECKOUT EQUIPMENT	TUG & TANK CHECKOUT SENSORS	0 G 15-16 PSIA 37°R	0 G 15-16 PSIA 37°R

Figure 9.4.4-1, Propellant Transfer Operations Control, presents a schedule of the events which will be used to control the propellant transfer cycle. After the propellant tank ullage pressure level of the total system has been established within the operational range to meet the system NPSP requirements, the prechill cycle indicated on Figure 9.4.4-1 will be initiated. The propellant flow control valves will provide a 10-to-1 throttling range to modulate the propellant flow during the prechill and topping periods and to provide full flow rate during the fast fill period. These control valves will also be used to control the flow rate to minimize residuals during the final phase of the second transfer as indicated on Figure 9.4.4-1. At the conclusion of the transfer the systems will be secured and prepared for independent operation of the tug and logistic module and the post transfer checkout will be conducted (Item 20). The cross-plane thrusting will be terminated at the optimum orbital position following the completion of the propellant transfer.

At this time, rendezvous of the orbiter with the tug and logistic module (Item 21) will take place. Items 21 through 33 (Figure 9.4.2-4) outline the principal steps involved in reloading the propellant module into the cargo bay and transferring the payload from the orbiter cargo bay to the tug. After the payload delivery has been accomplished (Item 33), the complete propellant transfer cycle will be repeated to transfer the propellant remaining in the logistic module into the tug for orbital makeup and storage for the next mission. These steps are outlined in Items 34 through 58. The orbiter will be returned for a landing at the proper time to meet the landing window requirements (Item 59).

9.5 PROPELLANT LOGISTICS INTERFACES DESCRIPTION

Summary information developed during the ISPLS interface analysis with respect to the logistic system selected is presented in the section that follows. Physical interfaces reviewed include mounting structure, fluid lines, electrical connections, and docking mechanisms between the logistic tank system and the user and orbiter vehicles.

As shown in Figure 9.5-1, the major propellant logistics key interfaces are between the logistic module and orbiter, logistic module and user vehicles (tug, CIS, and RNS), and all elements and ground facilities. This section of the report will be mainly concerned with the interfaces between the logistic module and orbiter and between the logistic module and user vehicles.

Preliminary interface requirements have been identified between the logistic module and launch facilities, logistic module and orbiter cargo bay, logistic module and space-based tug, logistic module and CIS, and logistic module and RNS. The logistic module inboard profile drawing (see Figure 9.1-1) identifies the major structural interfaces between the logistic module and cargo bay and logistic module and user vehicles. Also, the selected fluid interface line sizes are indicated.

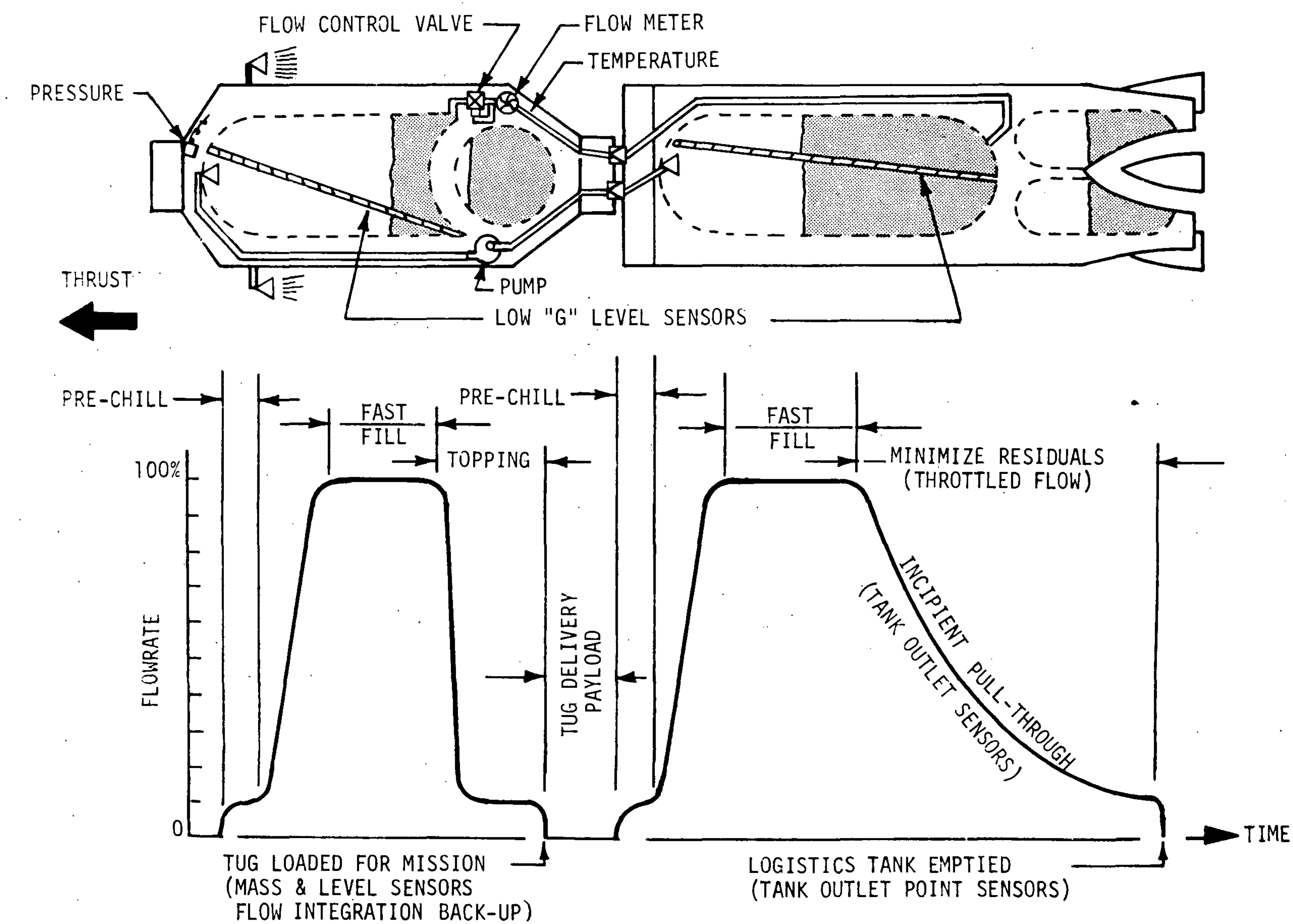


Figure 9.4.4-1 Propellant Transfer Operations Control

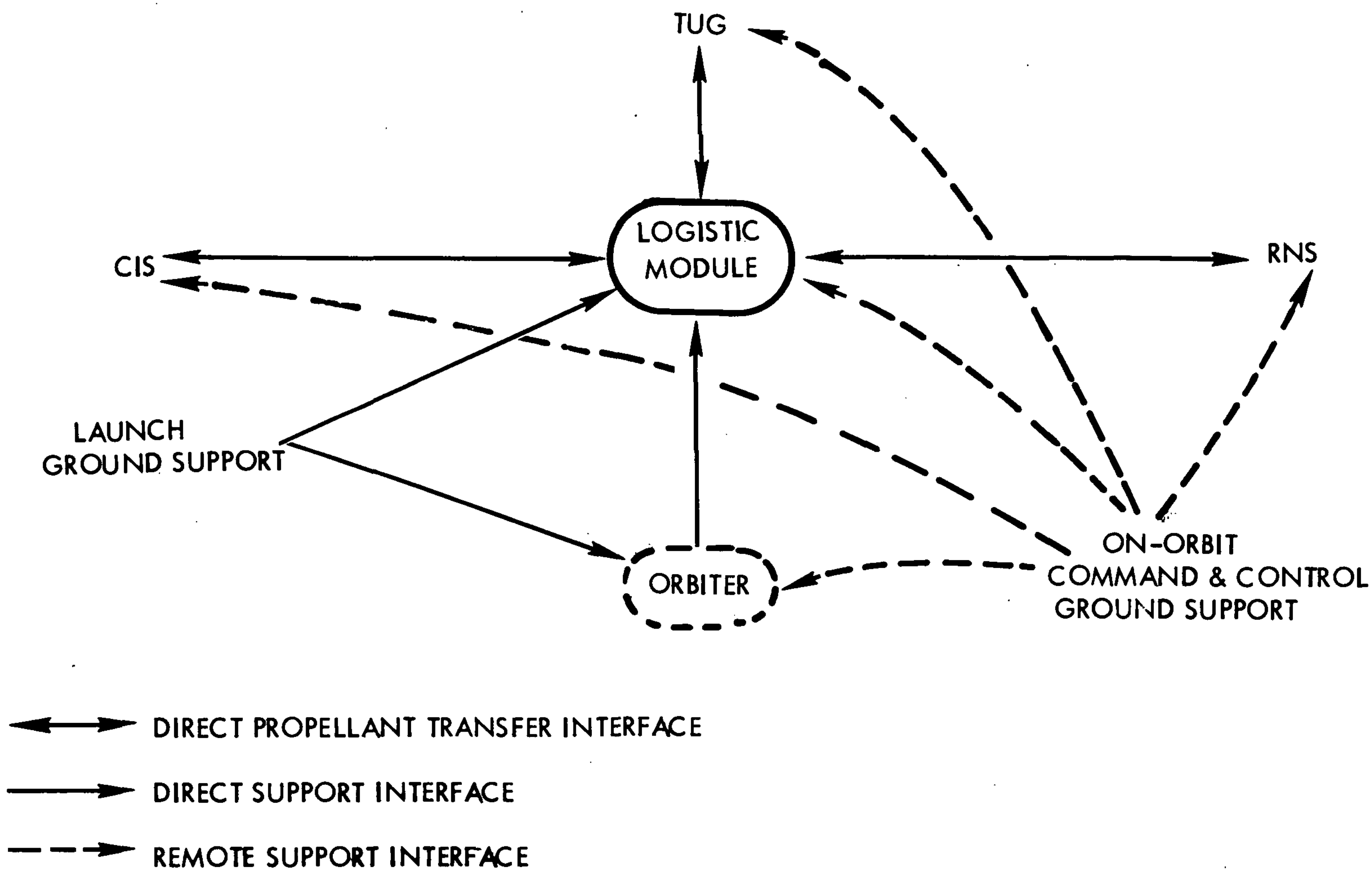


Figure 9.5-1 ISPLS Major Key Interfaces

9.5.1 Cargo Bay/Logistic Module Interface

9.5.1.1 Functional Interface Requirements

Analysis of the orbiter and logistic module system requirements and designs resulted in the following orbiter cargo bay/logistic module functional interface requirements. These requirements are based on a tug supportive logistic module; however, CIS or RNS supportive logistic module requirements would be very similar and in many cases identical.

a. Command and Control - consists of commands and responses required during ground and pre-deployment checkout and for operational control of the logistic module. Approximately 90 signals (estimated) would be required to command and control valves, pumps, docking latches, line interconnect fixtures, linear acceleration jets and other systems.

b. Hazard Monitoring - includes instrumentation signals required for hazardous condition monitoring, equipment monitoring, and checkout. The number of signals is estimated to be approximately 40 and would monitor tank pressures, tank temperatures, hazard gas concentration, latch position, etc.

c. Electric Power - consists of wiring required for the orbiter to supply power to the logistic module (approximately 5 wires).

Voltage:	28 $\pm$ 2 VDC
Peak Power:	Approximately 500 watts
Energy:	Approximately 3 KW-H

d. Structural - attach points for retention of logistic module in cargo bay.

e. Insulation Purge - logistic module multi-layer insulation (MLI) purge required during ground operations.

f. Insulation Vent - logistic module MLI vent required during boost and while on-orbit.

g. Insulation Pressurization - logistic module MLI pressurization required prior to re-entry.

h. Cargo Bay Purge - unused cargo bay area is required to be purged of hazardous gases and contamination during pre-launch.

i. Propellant Ground Fill and Drain - logistic module is filled and drained while in cargo bay on launch pad.

j. Propellant Ground Vent

k. Propellant Ground Drain Pressurization

l. Propellant On-Orbit Vent

m. Propellant On-Orbit Dump

n. Propellant Boost Vent

o. Tank Ground Purge

p. Manipulator Arms - used to assist logistic module docking to or undocking from user vehicles.

q. Docking Fixture (swing-out deployment ring)

r. Emergency Tank Vent

9.5.1.2 Physical Interface Description

The attachment interface of the propellant logistic module with the orbiter cargo bay is based on attach fixtures and locations as proposed by the NR shuttle design study. The proposed attachments are illustrated in Figure 9.5.1-1. Four attach points are provided for payload retention. Three would be located at the same fuselage station, consisting of two side trunion fittings to carry fore and aft and vertical loads and one lower fitting to carry side loads. The fourth would be at a fuselage station nearer the other end of the logistic module and would be a side trunion fitting to react vertical loads. In this arrangement the deflections of orbiter structure would be accommodated without transmitting loads to the payload. Six optional station locations for the retention fittings are proposed (additional locations could be specified) along the 15-foot-diameter by 60-foot cargo envelope.

Figure 9.5.1-2 shows the cargo bay interface of the tug supportive logistic module. The module is located in the aft two-thirds of the bay. Retention fittings are at stations 995 and 1215 with the three primary load fittings very close to the module c.g. (when full). Payloads carried on the same flight would be separately attached in the forward part of the cargo bay. A swing-out ring is shown on the aft end of the module for use in deployment of the module in orbit. Unlike similar rings proposed by other cargoes (ground-based tug, RAM, etc.) this ring does not aid in supporting the module in the bay. The figure also shows a plot of the tank module c.g. during dumping of propellant in an abort case. Location of the c.g. in the cargo bay is of concern to the orbiter handling characteristics.

The cargo bay interface for a CIS supportive logistic tank module would be similar to that for the tug supportive module. Due to the slight additional length of the CIS supportive module, optimization of support locations would create a preference for the retention fittings to be approximately 2 feet forward of station 995 (not one of the primary locations proposed by shuttle).

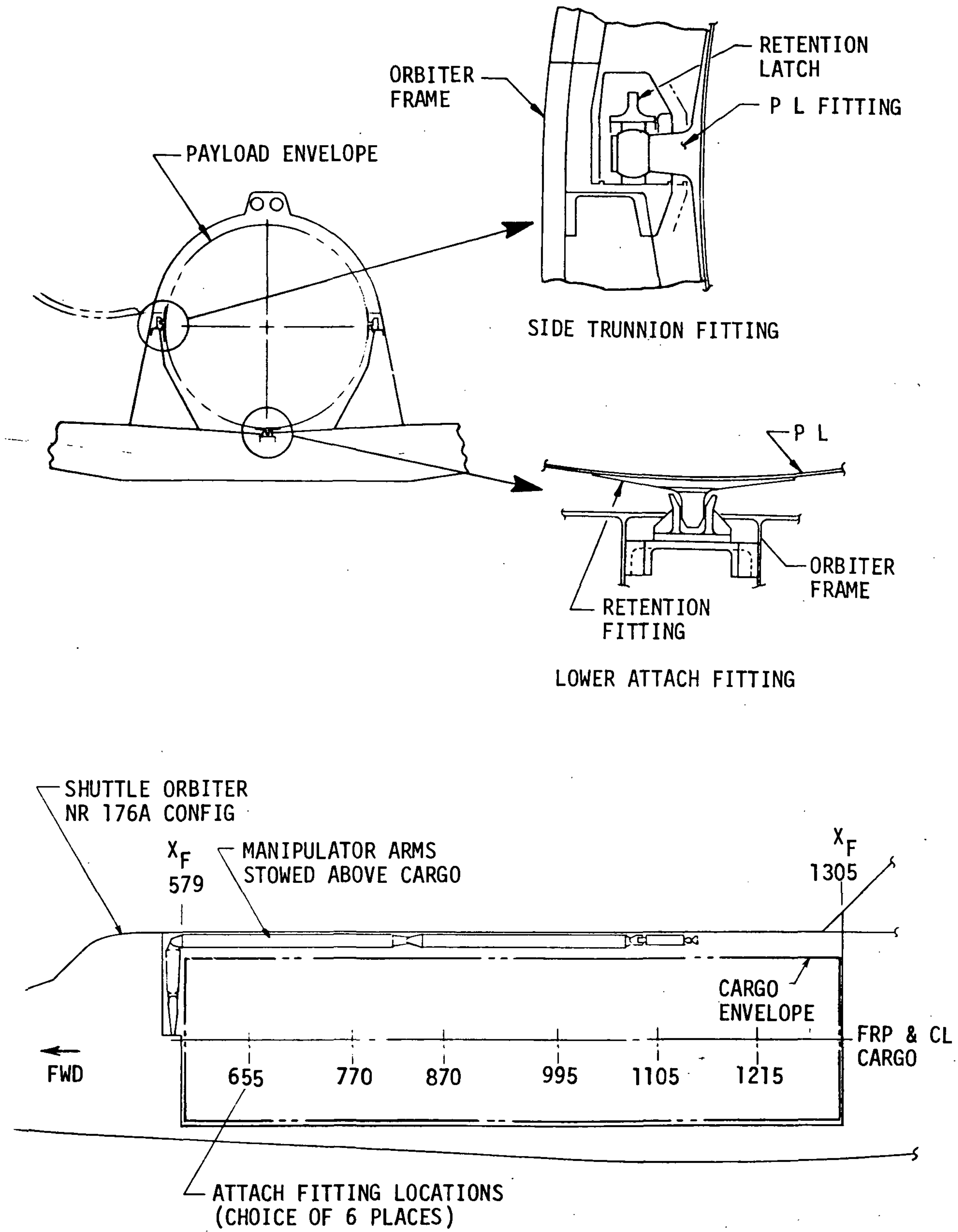


Figure 9.5.1-1 Orbiter Cargo Attachment Requirements

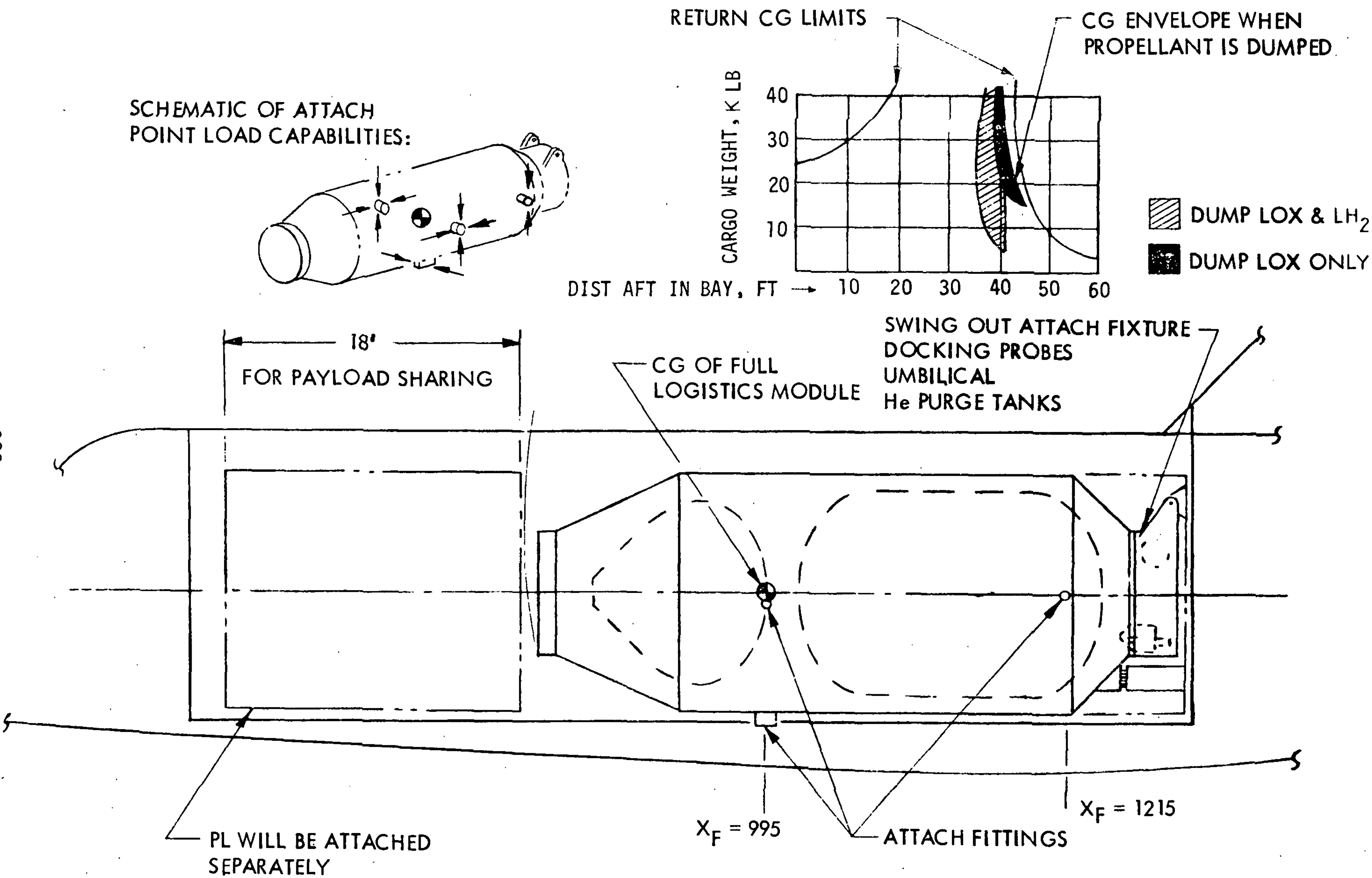


Figure 9.5.1-2 Cargo Bay & Logistic Module Attachment Interface

Figure 9.5.1-3 shows the cargo bay and RNS supportive logistic module attachment interface. The primary retention fittings are shown at orbiter station 870 which is a compromise to keep the supports near the c.g. (so that vertical loads will not require a large reaction at the aft fitting) and to keep the supports for the boost loads near the tank supports at the forward end of the module. As in the other modules the fittings provided on the exterior of the logistic module shell will be the type defined by the orbiter retention system design. These fittings extend beyond the limits of the 15 ft. diameter cargo envelope.

Deployment of the propellant logistic module will be accomplished by a swing-out ring and the orbiter manipulator arms. The swing-out ring will be for zero "g", with the hinge pin removed during flight. This ring will house the docking system and the on-board purge (insulation repressurization) storage bottles. The interconnect for the purge lines and the electrical lines will be on the swing-out ring. Thus the purge fluid lines will not have to flex as the ring is deployed (since the storage bottles move with the ring) and the electrical interface will remain intact while the logistic module is in the deployed (but not yet released) position.

Deployment of the ring, with logistic module attached, and stabilization of it in the deployed position can be accomplished by an extension mechanism at the ring. Stabilization while the logistic module is deployed is necessary to free the manipulator arms for other use in the deployment and docking operation.

The line interconnections with the cargo bay umbilical will be made at the aft end of the logistic module and will be separate from the user vehicle transfer line interconnect mechanism which is located at the forward end of the logistic module. The active (line extension mechanism) side of the umbilical line interconnect for all orbiter logistic module rematible lines will be in the orbiter cargo bay, not part of the logistic module, but will be considered part of the cargo. This mechanism will be powered and actuated by hard wire signals from the orbiter.

The mechanism will consist of an extendable frame capable of engaging and aligning with the receptacles in the logistic module upon its return to the cargo bay. The orbiter/logistic module interface will consist of six mechanisms; two for H_2 lines, two for electrical connectors and on-board repressurization, and two for LO_2 and remaining lines. Because of the critical nature of these lines, two of each are required for redundancy.

The logistic module docking interface with the swing-out ring in the orbiter will be similar to that proposed for the point design tug. These probe and drogue type fixtures will attenuate, align, and capture the logistic module as it is returned to the orbiter. The probes will draw the module into its final docked position and a series of eight latches will firmly attach the module to the swing-out fixture.

External fittings on the logistic module, of the type proposed by the orbiter, will be provided for attachment of the orbiter manipulator arms to assist in deployment and docking.

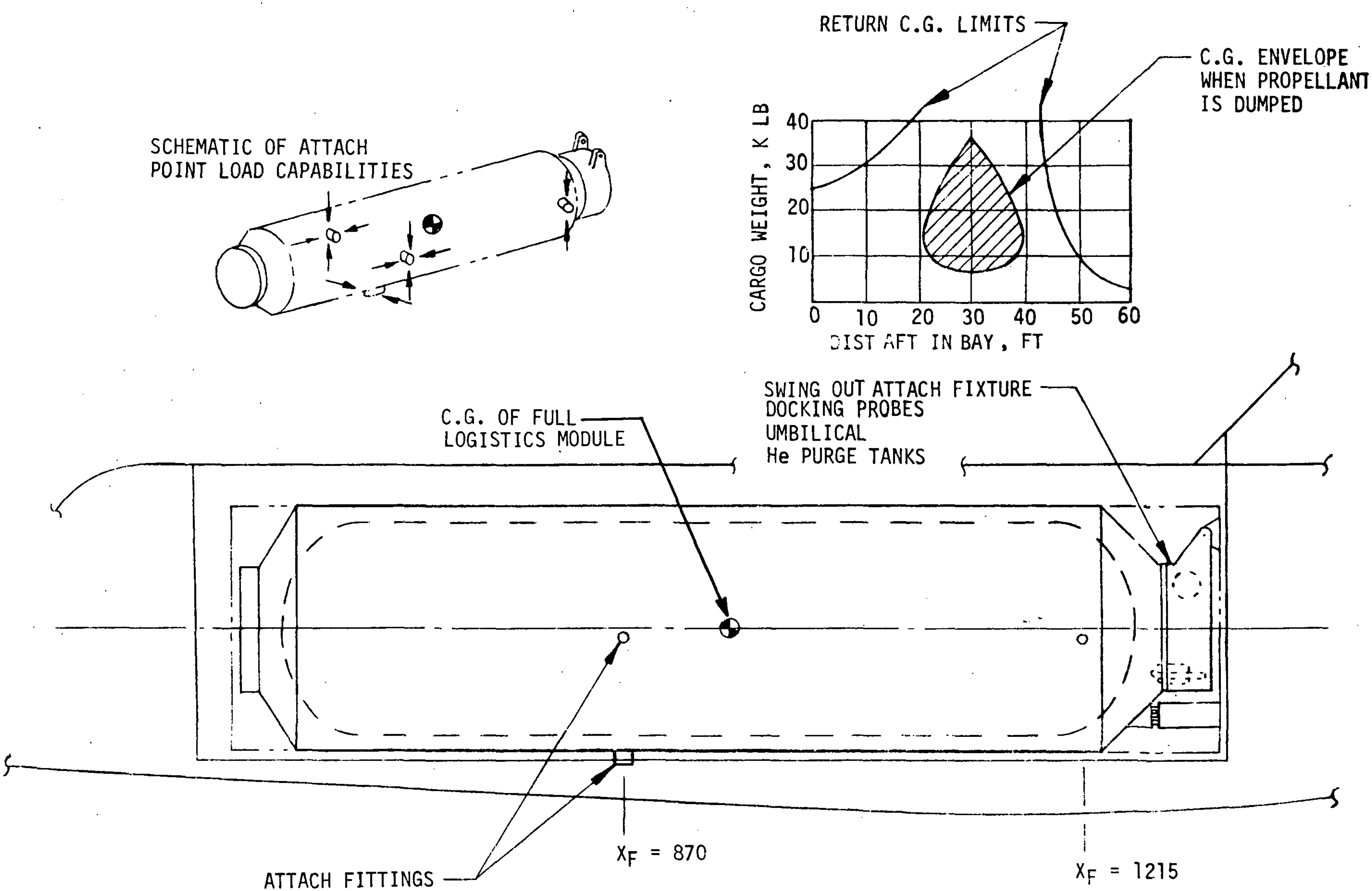


Figure 9.5.1-3 Cargo Bay & RNS Logistic Module Attachment Interface

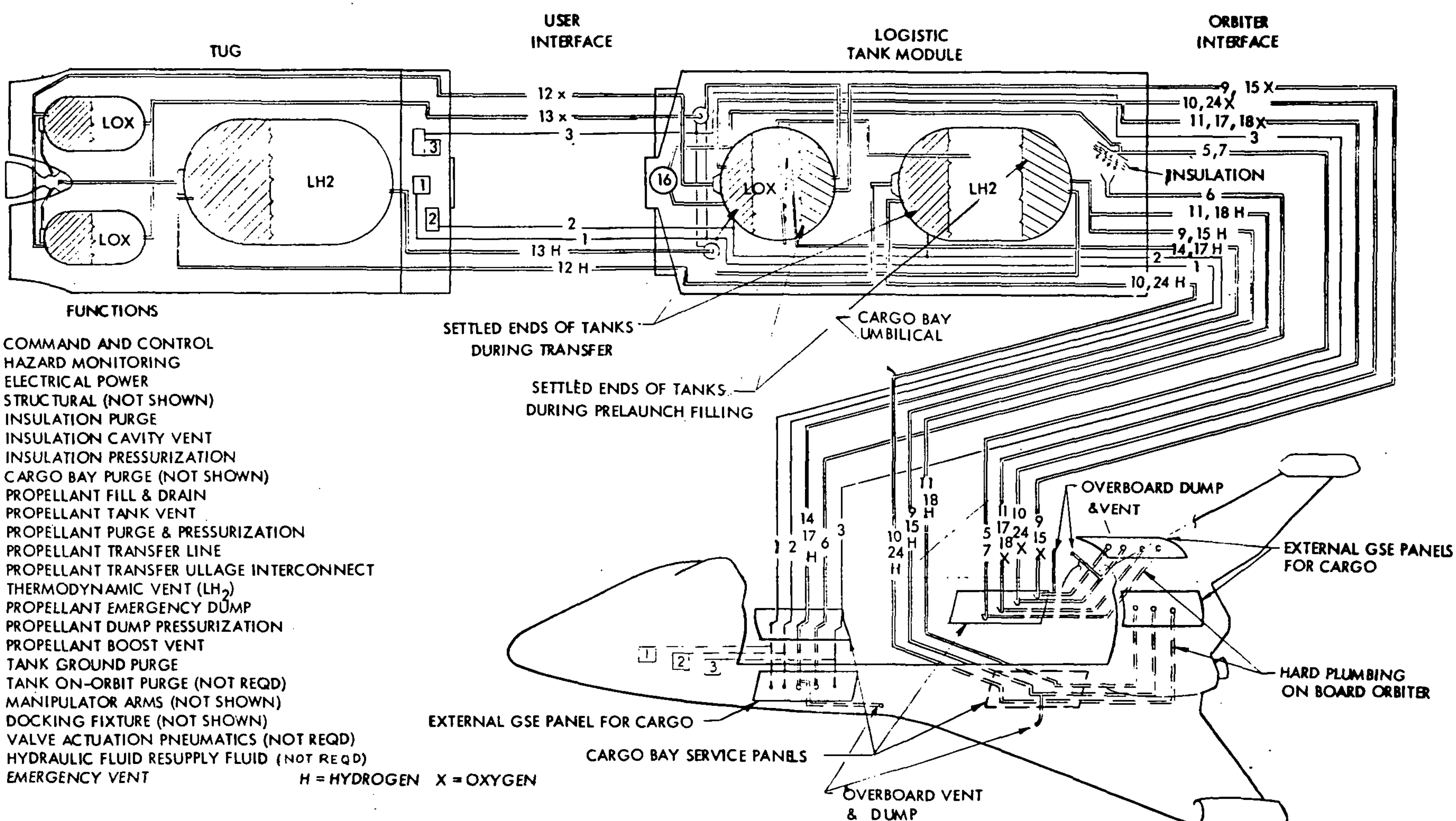
The fluid line and electrical interfaces of the logistic module with the orbiter and with the tug are shown in Figure 9.5.1-4. The orbiter interfaces can be traced thru the on-board plumbing to the GSE external service panels and some lines are shown branching off to connect with orbiter systems. Thus the schematic will aid in illustrating the logistic module interface requirements to those planning the orbiter cargo interfaces. The locations of service panels, line runs, dumps, and vents are not necessarily intended to reflect actual location requirements. It is anticipated that a cargo bay umbilical will be installed as a kit for propellant logistics missions and will join the cargo bay service panels (wherever located) with the logistic module interfaces. Table 9.5.1-1 presents the nominal diameter for each of the physical fluid interfaces between the logistics module and the cargo bay. The disconnect numbers refer to the logistic module schematic presented in Section 9.1.

The nine fluid lines and three electrical connectors seem to make the cargo bay interface complex, but they represent the minimum connections required for fill, drain, vent and pressurization of both logistic module tanks, insulation purge and vent, and logistic module monitoring and support. As shown by the functional designations coded to the lines, most lines are used for more than one function. Since there are no current provisions for direct attachment of GSE umbilicals to the logistic module (while the logistic module is in the cargo bay with the cargo bay doors closed), these interconnects must be made with plumbing provided by the orbiter, and lead to the orbiter's external GSE panels. Receptacles will be provided on these panels for cargo servicing. It is expected that these same functions will be provided similarly for several other cryogenic payloads anticipated for the orbiter. The hydrogen on-orbit dump (15H) is shown (combined with the LH_2 fill line) but it may be determined that hydrogen will not be dumped in an abort condition. In that case, the hydrogen overboard dump shown on the orbiter would not be required.

Several of the line interfaces with the cargo bay will have to be reconnected after the logistic module is returned to the orbiter following completion of propellant transfer to a user vehicle. These include the electrical lines (1, 2 and 3), insulation purge and vent (5 and 6), and emergency vents (24) for both LO_2 and LH_2.

Redundancy requirements for the interconnects are not reflected in the schematic. It is expected that the critical interconnects which must be remated upon return of the logistic module to the cargo bay will have to be redundant.

No fluid lines are shown for valve actuation pneumatics or hydraulic fluid resupply (functions 22 and 23). It is anticipated (but will not be currently verified) that user vehicles will require resupply of these fluids as well as the primary propellants, and they were included on the list for that reason. If it is determined in a more detailed follow-on definition of the logistic module that pneumatic valve actuation is required by the propellant transfer system, it would be combined with the on-orbit dump pressurization system and helium bottle (16) and the function (22) to fill the bottle(s) would be added to the existing insulation purge and pressurization line (5 & 7) thru the cargo bay umbilical.



FUNCTIONS

1. COMMAND AND CONTROL
2. HAZARD MONITORING
3. ELECTRICAL POWER
4. STRUCTURAL (NOT SHOWN)
5. INSULATION PURGE
6. INSULATION CAVITY VENT
7. INSULATION PRESSURIZATION
8. CARGO BAY PURGE (NOT SHOWN)
9. PROPELLANT FILL & DRAIN
10. PROPELLANT TANK VENT
11. PROPELLANT PURGE & PRESSURIZATION
12. PROPELLANT TRANSFER LINE
13. PROPELLANT TRANSFER ULLAGE INTERCONNECT
14. THERMODYNAMIC VENT (LH_2)
15. PROPELLANT EMERGENCY DUMP
16. PROPELLANT DUMP PRESSURIZATION
17. PROPELLANT BOOST VENT
18. TANK GROUND PURGE
19. TANK ON-ORBIT PURGE (NOT REQD)
20. MANIPULATOR ARMS (NOT SHOWN)
21. DOCKING FIXTURE (NOT SHOWN)
22. VALVE ACTUATION PNEUMATICS (NOT REQD)
23. HYDRAULIC FLUID RESUPPLY FLUID (NOT REQD)
24. EMERGENCY VENT

H = HYDROGEN X = OXYGEN

Figure 9.5.1-4 Logistic Module (Tug) Line Interface Schematic

Table 9.5.1-1 Logistics Module to Cargo Bay Fluid Interfaces

DISC. NO.	FUNCTION		NOM. DIA. (INCHES)
27 & 32	TANK PURGE & DRAIN PRESS.	(LH_2 & LOX)	1
29 & 33	FILL, DRAIN & EMERG. DUMP	(LH_2 & LOX)	3
30 & 34	TANK VENT	(LH_2 & LOX)	3
35	THERMODYNAMIC VENT SUBSYSTEM	(LH_2)	1/2
28	INSULATION PURGE	(GHe)	1/2
31	INSULATION CAVITY VENT VALVE	(MISC)	1

As indicated earlier in this section, the orbiter will be required to provide many of the avionics functions necessary for proper operation of the logistic module while it is attached. It was decided during this study, that since the orbiter would have this capability, a minimum avionics hardware philosophy would be adopted in configuring the logistic module. Therefore, the logistic module will be dependent upon the orbiter's data management system to provide exchange data for safety and module status checks, verification of logistic module operational parameters, and on-board checkout prior to deployment and re-entry. Also, command, control, and monitoring must be provided during ground tanking (propellant gauging data), deployment, and docking. All electrical interfaces between the orbiter and logistic module minimum avionics hardware system will be hard wired. Presently, the orbiter design allows for an eight square foot by twenty inches deep payload control and display panel aboard the orbiter. This appears to be sufficient unless the payload (shared with the logistic module) is extremely complicated.

The type of data required to be monitored by the orbiter would include: propellant level and temperature, ullage pressure and temperature, vibration measurements, valve position, holddown retention status, docking latches position, and other miscellaneous analog and discrete measurements.

Also, the logistic module will be dependent upon the orbiter communications system to transmit data to and receive commands from ground stations on a noninterference basis with orbiter operational requirements. At this stage of the study, sharing of the orbiter communications system seems to be feasible and satisfactory.

Presently, the orbiter is designed to supply electrical power to a cargo as specified below:

<u>DC Power Characteristics</u>

28 $\pm$ 2 VDC

500 watts (average)

800 watts (peak)

20 KW - Hours (energy)

2 Separate DC buses

<u>AC Power Characteristics</u>

115/200 VAC

3 Phase

400 Hz

Energy levels would subtract from above DC Power energy levels

Note : Electrical signal and power grounding will be determined by the orbiter design.

The estimated DC power requirements of the logistic module fall within the capability of the orbiter as indicated above. The only known logistic module AC power requirement would be for the propellant transfer pumps if it were necessary to check them prior to deployment.

In general, it appears that the final design of a logistic module would be compatible with all orbiter and cargo bay environments such as temperature, sound level pressure, vibration, shock, and electromagnetic interference. Also, the orbiter is capable of providing a cargo bay purge system to reduce hazardous gas concentration.

9.5.2 Logistic Module/User Vehicle Interface

9.5.2.1 ISPLS Docking Requirements

The selected concepts and operational modes of propellant logistics do not impose severe requirements or restrictions on the docking fixtures of the interfacing vehicles. While recognizing the desirability of docking commonality, propellant logistics considerations do not drive the elements of the space program toward commonality of docking fixtures. The selected propellant logistics concept contains no orbital storage depot that has to have the different space-based user vehicles interface at the same port. The propellant requirements are different for the tug, the CIS and the RNS in that the RNS uses all hydrogen and that the CIS requires additional LH_2 to make up for boiloff during the prolonged propellant delivery process. These and other differences in tank module design requirements (such as the thrust level required for propellant settling due to different user masses) indicate that there would be a different logistic tank module for each of the users. Therefore, the logistic module can be designed to match whatever docking fixture is chosen by the user vehicles and does not set a requirement for docking commonality.

For the purpose of defining the logistic tank modules, the docking fixtures as proposed on the user vehicle configurations will be used. In the case of the Apollo fixture (on the tug) it should be noted that a method of keying the modules in a closely controlled roll orientation would have to be added. (The Apollo fixture does not align the mating halves with respect to roll.) This would be necessary to orient the line interconnects and receptacles in line with each other.

9.5.2.2 User Vehicle Docking Fixtures

As a starting point for the definition of docking interfaces between the logistics tank module and the user vehicles, the docking and propellant transfer provisions proposed by the previous studies for those vehicles will be shown.

The ISPLS baseline space-based tug is considered to have propellant transfer docking at its forward end. The vehicle definition from the tug study showed an aft docking port and would have had propellant transfer there. That configuration was based on considerations of manned operation and conversion to lunar lander operations, considerations that the ISPLS study does not feel will be imposed on future definitions of an earth orbital operations tug. It is felt that, in the interest of improved mass fraction, the four-engine configuration will give way to a single or perhaps two-engine tug, which would all but preclude aft docking. Therefore, to be compatible with the more likely configurations of a space-based tug, forward docking is considered baseline.

The forward docking interface of the space-based tug is shown in Figure 9.5.2-1. Apollo docking fixtures were chosen by the tug study to show the capability to adapt available hardware and because they are much lighter than the larger docking fixtures being proposed (as for space station) at that time. The probe is shown on the tug which allows the small, lightweight passive drogue to be on the payloads. The probe has attenuation, capture and pull down capability.

It is supported by added struts backed by a 7 foot diameter, short cylindrical structure. Propellant transfer line receptacles were not shown at the forward docking interface. Additional attach latches to retain a payload (if necessary) or a propellant module were not defined on the tug configuration but were anticipated to be added when the requirements are known.

The CIS docking interface is shown in Figure 9.5.2-2. A seven-foot ring-cone-fixture (that was being defined and proposed in the space station study) was used, mostly in the interests of commonality. It has a desirable feature of being androgynous, permitting docking between vehicles with the same active fixtures such as a tug retrieving a CIS. The CIS has the active neuter fixture allowing a payload or propellant tank to have a compatible passive fixture. The active fixture has the attenuation, capture and pull down capability. Attach latches could be a part of the basic docking fixture, located at the 7 foot diameter ring, or could be located elsewhere (such as the 15 foot diameter ring, depending on payload attach requirements). Propellant transfer line receptacles were not defined by the CIS study.

The RNS docking interface is shown in Figure 9.5.2-3. It also uses the seven-foot ring-cone fixture with the same rationale and features given in the preceding paragraphs. The RNS study did not specify a location for attach latches other than those that could be a part of the 7 foot fixture. Propellant transfer line receptacles were not defined.

9.5.2.3 Logistics Module/User Vehicle Electrical & Fluid Line Interfaces

Preliminary definitions of the line interconnect interfaces between the logistic modules and the user vehicles provide a basis for future planning and design of the user vehicles. (See Figure 9.5.1-4). The tug, CIS and RNS line interfaces are quite similar. In each case, two line interconnect mechanisms extend from the logistic module to engage the transfer lines in

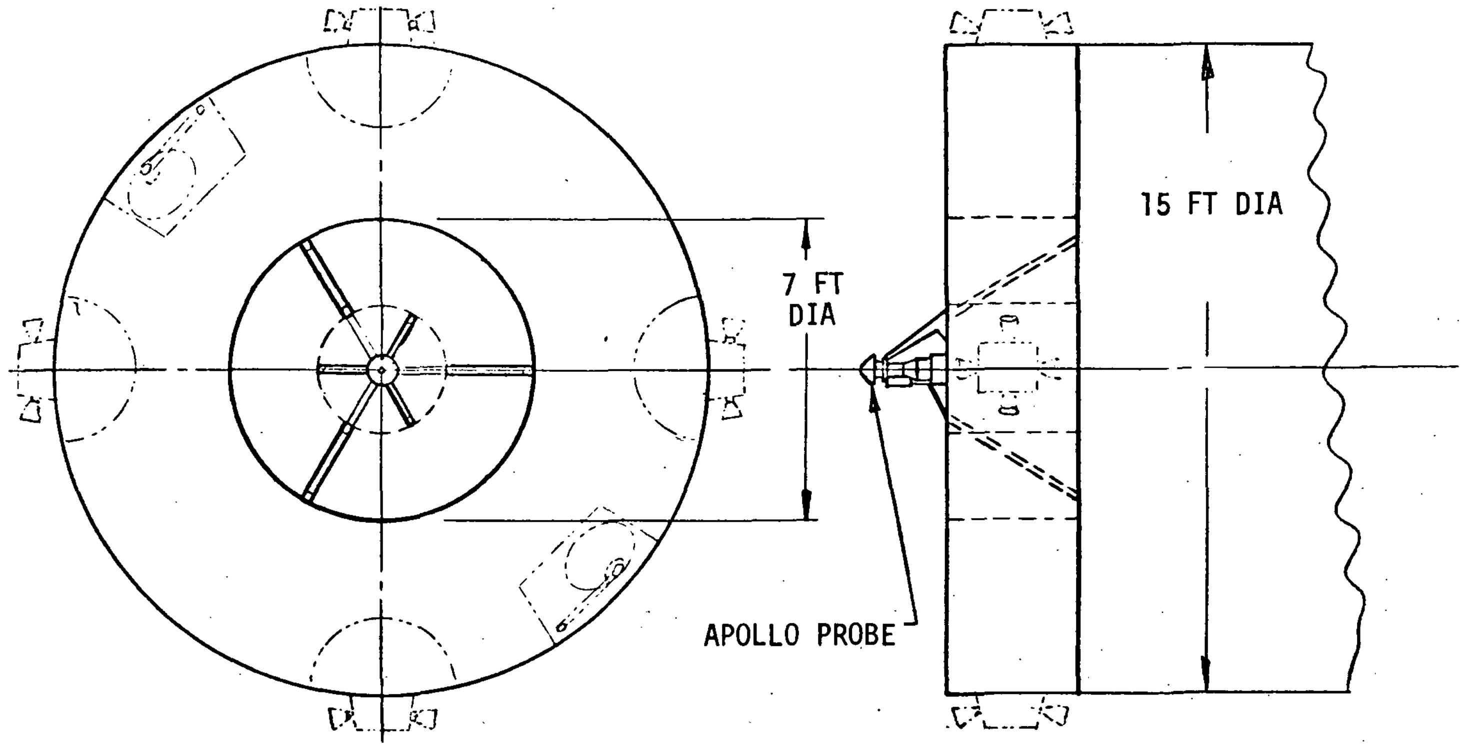


Figure 9.5.2-1 Space Based Tug with Apollo Probe

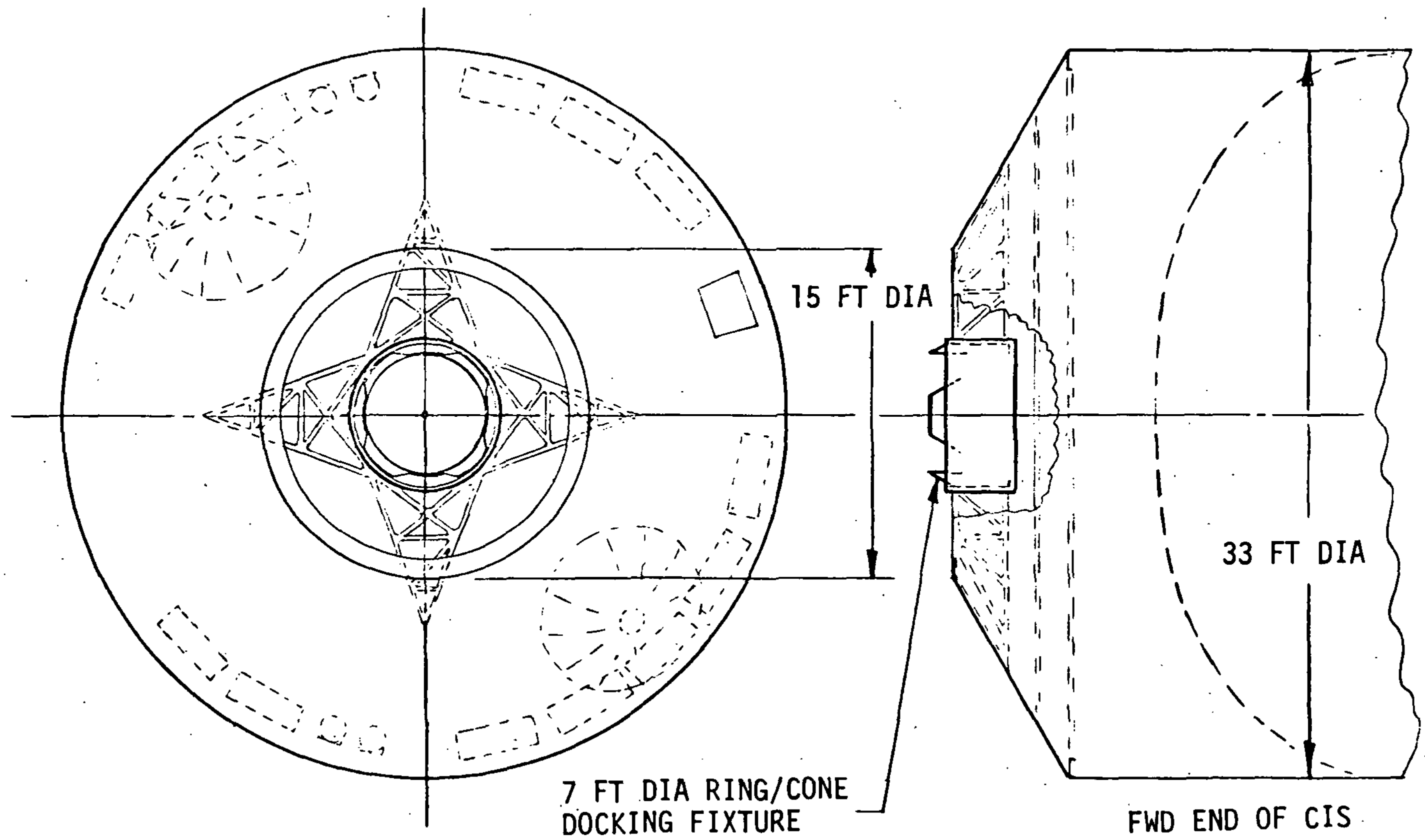


Figure 9.5.2-2 CIS with Ring/Cone Docking Fixture

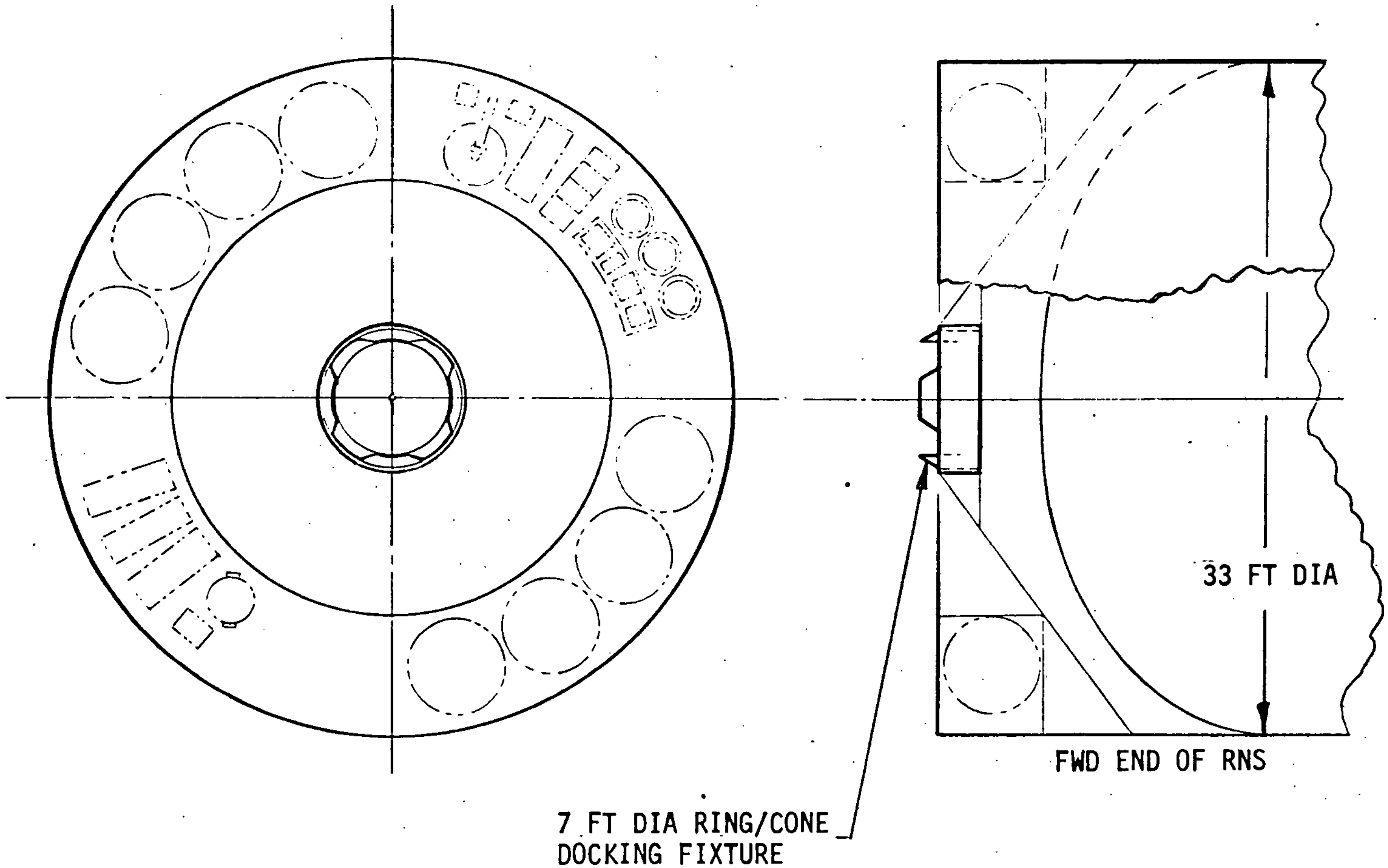


Figure 9.5.2-3 RNS with Ring/Cone Docking Fixture

the receptacles provided by the user. The interconnects are outside the 7 foot docking ring and diagonally opposite each other. A second pair of interconnects is shown on the module to provide redundancy since a failure to make the connections would be a mission failure at the cost of the shuttle flight. The single pair of receptacles in the user is engaged by redocking the module in a different roll orientation. The electrical connectors are shown on the interconnect with the LH_2 lines as the least hazardous location for operation in space.

Figure 9.5.2-4 shows the tug interface. Interconnects are located close in to the 7-foot ring; the exact location would be determined by coordination of design between future logistic module and tug design effort.

The CIS interface is shown in Figure 9.5.2-5. Due to the structural arrangement of the docking fixture support, the interconnects are further outboard in this configuration. As in the other interfaces, the receptacles should be kept fairly close to the same plane as the docking interfaces as indicated by the (less than 8") dimension. This would allow sufficient recessing to avoid contact during docking and to provide for a cover. The cover should be capable of being opened after the vehicles are docked.

Figure 9.5.2-6 shows the RNS interface. Though the RNS engine operates on hydrogen only, the interface shows the LO_2 interconnect since small amounts of oxygen would be required by the fuel cells and attitude control system.

Table 9.5.2-1 shows practical propellant transfer line sizes for each user vehicle and the associated time for one nominal logistic module transfer. Also, the nominal pumping power required for these line sizes and transfer times are indicated in the table.

Table 9.5.2-1 Transfer Line Sizes

TUG (10 Hours)		CIS (15 Hours)		RNS (15 Hours)	
Supply Line (I.D.)	Gas Return Line (I.D.)	Supply Line (I.D.)	Gas Return Line (I.D.)	Supply Line (I.D.)	Gas Return Line (I.D.)
LH_2 1 1/2" (0.2 HP) (150 watts)	3/4"	LH_2 1 1/2" (0.1 HP) (75 watts)	3/4"	LH_2 2 1/2" (0.36 HP) (270 watts)	1 1/2"
LOX 1 1/2" (0.1 HP) (10 watts)	3/4"	LOX 1 1/2" (0.1 HP) (10 watts)	3/4"	LOX 1 1/2" (0.1 HP) (10 watts)	3/4"

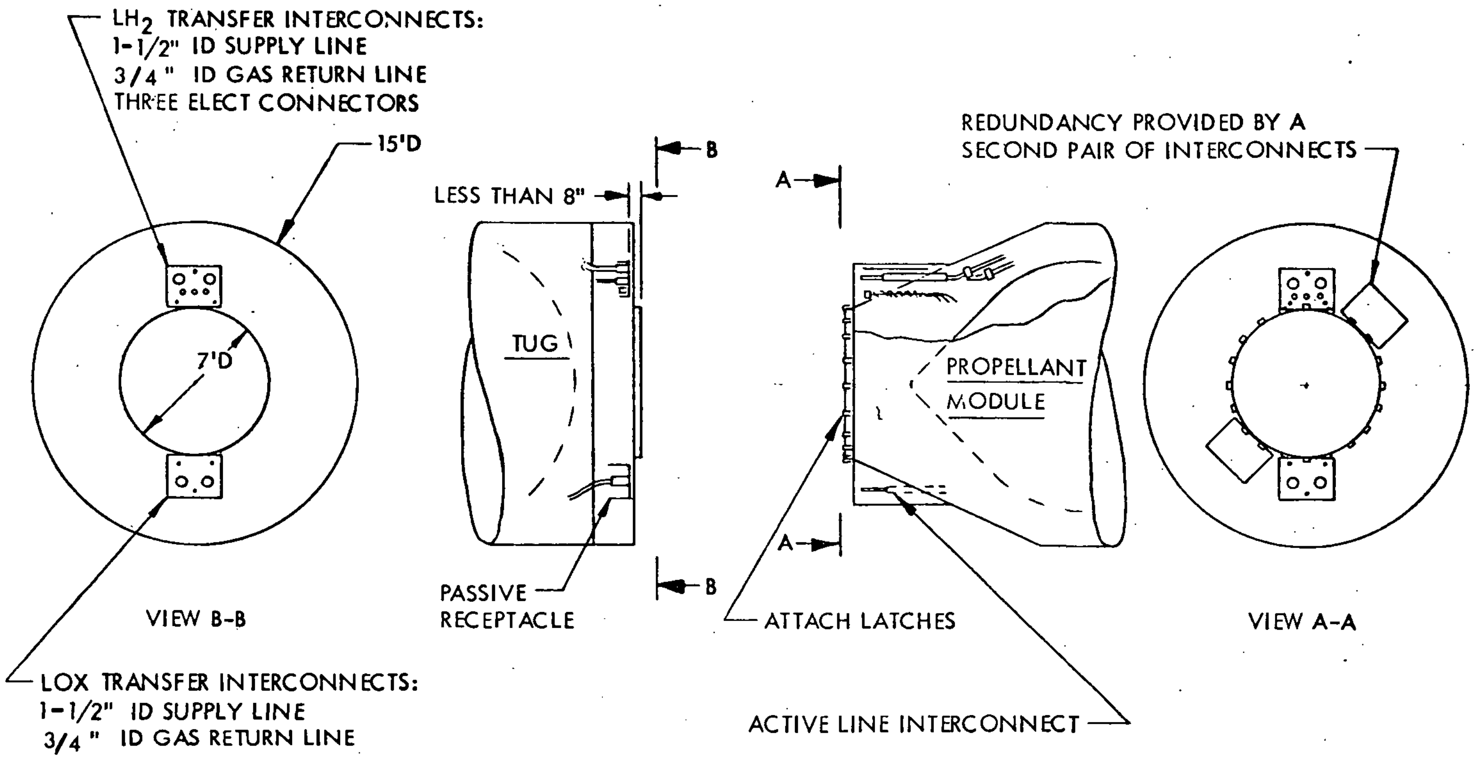


Figure 9.5.2-4 Propellant Transfer Line Interface With Tug

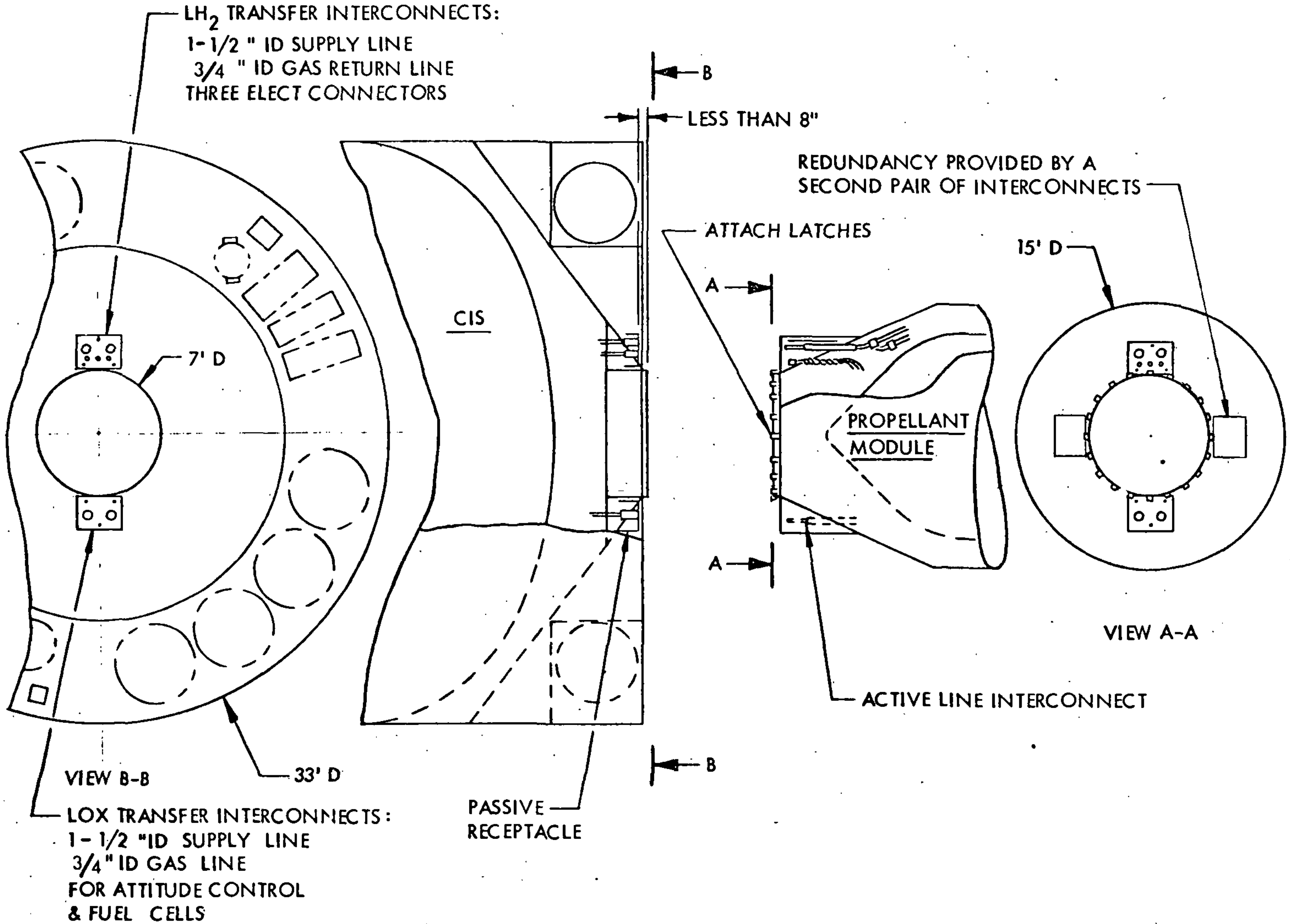


Figure 9.5.2-5 Propellant Transfer Line Interface with CIS

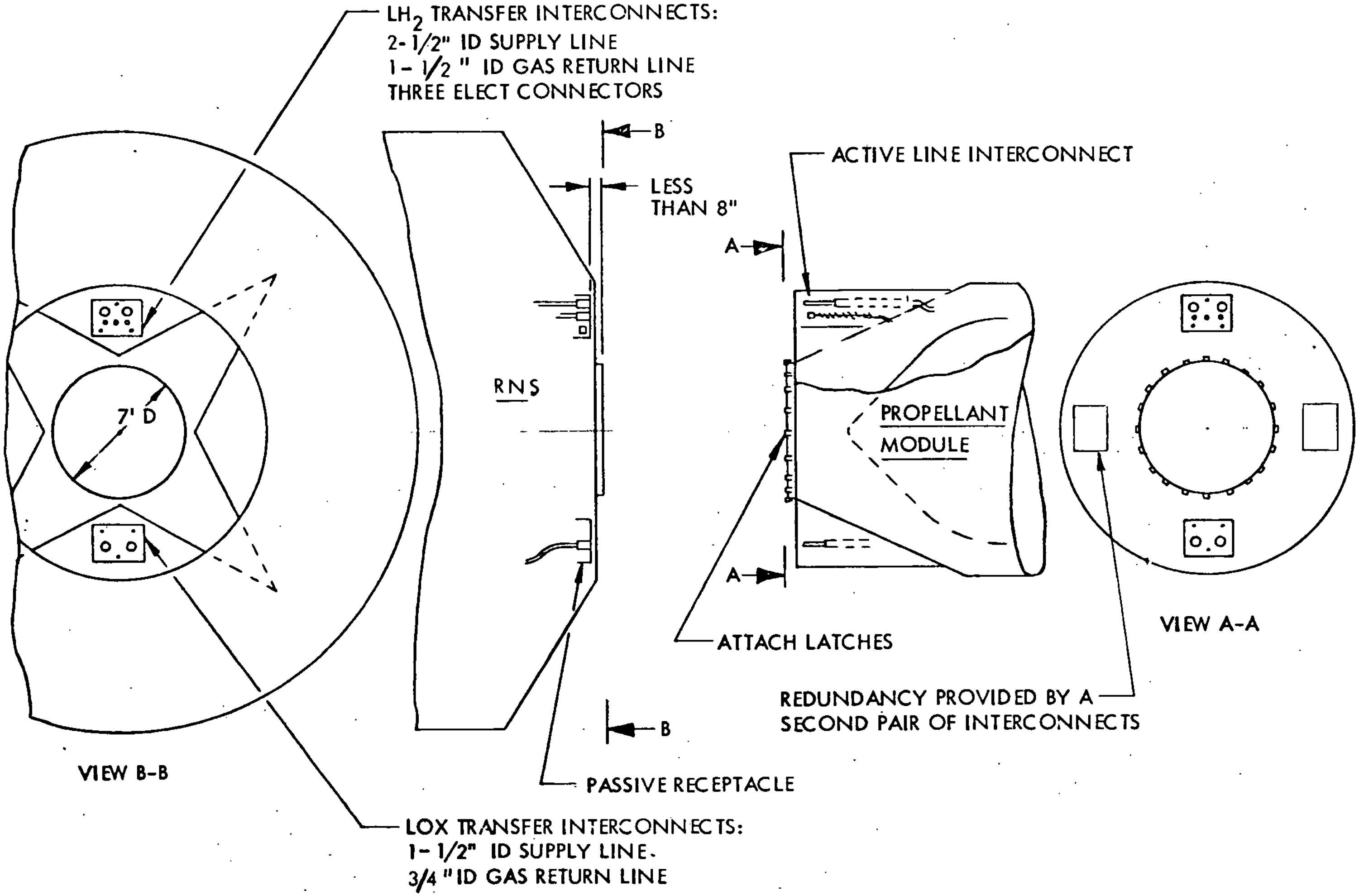


Figure 9.2.5-6 Propellant Transfer Line Interface With RNS

The logistic module/user vehicle line interconnect mechanism will be similar in design and operation to those described for the cargo bay/logistic module rematible interfaces. Also, as in the case with the orbiter, the logistic module will be dependent upon the user vehicle to provide the avionics functions necessary for proper operation of the logistic module during propellant transfer. Again, this will be a hardwired electrical interface.

Therefore, the logistic module will require the use of the user vehicle data management system and communications system for the same functions discussed under the orbiter/logistic module interface requirements. Also, the logistic module will be dependent upon user vehicle guidance and navigation systems to provide hardwired electrical signals for operation of the linear acceleration (propellant settling) thrusters. The thrusters and thruster propellants will be located on the logistic module but all calculations and control must be derived from the user vehicle.

The user vehicle must supply electrical power to the logistic module during the entire period they are docked. The type of power will be the same as discussed under the orbiter/logistic module interface section for AC and DC, with AC peak power levels as indicated in Table 9.5.2-1 for a particular user vehicle. However, the total energy level (approximately 8 KW-hours for the tug) will be greater due to the longer time period and the AC power required for pumping.

In summary, it appears feasible for the final design of a logistic module to be compatible with all interface requirements of the particular user vehicle with which it will mate.

9.6 DETERMINATION OF IN-SPACE MAINTENANCE REQUIREMENTS

Maintainability of the propellant logistics module (tank) is an important design requirement to minimize the number of tanks in the logistics program. These requirements apply equally to ground and flight phases of the module's life. The ground phase requires a turnaround of the module to be within the turnaround time in the shuttle - about 14 calendar days on a two-shift basis. The flight phase requires that maintenance activities in space be minimized due to the hazards and high costs relative to ground maintenance. However, some form of maintenance will be required to minimize the costs incurred in repeating logistics missions.

To satisfy these requirements, the module design incorporates features to minimize inspection, repair, and checkout times in the ground turnaround. For flight, critical subsystems have a remotely switchable redundancy capability. Thus, no spares or crew maintenance tasks are planned for in-space propellant transfer support during normal missions.

9.6.1 ISPLS Maintenance Requirements

Definition of terms:

- Maintenance - The tasks performed on equipment which sustain its performance within acceptable limits

- Maintainability - The capability of equipment to permit maintenance tasks upon it without requiring excessive down-time
- Maintenance Concepts - Plans for performing maintenance. To be realized, provisions for accomplishing these concepts must be incorporated in the equipment designs
- Scheduled Maintenance - Minor cyclic tasks required on certain equipment to prevent premature failures
- Unscheduled Maintenance - Maintenance tasks which arise from failure and which require repair, replacement, or redundant backup

Requirements for Maintenance

The two most feasible in-space propellant logistics concepts developed in this study are the ground-based (GB) tug concept and the space-based (SB) tug concept which provides storage for its own propellants. The GB tug concept maintenance requirements are similar to those for the SB tug since the equipment required for each is essentially the same. The SB tug with self-storage concept employs a ground-based logistics module for propellant resupply via shuttle between missions. A listing of the logistics module's subsystems and their failure rates (based on space operating times) are given in Table 9.6.1-1.

TABLE 9.6.1-1 MODULE SUBSYSTEMS RELIABILITY

Subsystems	λ- Failure Rate(1) per 10^6 Hours
Structure & Docking Port(s)	23.3
Insulation Panels	11.6
LO_2 Tank	.372
LH_2 Tank	.372
Attitude Control	1.93
Propellant Transfer & Lines	1.19
Meteoroid Protection	11.6
Propellant Quantity Gauging	9.17
Instrumentation	9.17
Propellant Fill, Drain, Safing & Venting	1.19

(1) Based on industry-wide experimental data and analytical extrapolation for performance of weakest component in subsystem

The failure rates indicate that the individual mission duration of the module is short compared with the expected lifetime of the module's components. Therefore, no scheduled or unscheduled maintenance is planned during normal orbital operations. However, since the failure rate is not zero, some in-flight failures will occur. These are particularly important where they have a direct impact on propellant transfer or tank recovery. To maximize mission success, unscheduled maintenance will be required on loaded tanks. This may be accomplished either through redundancy, removal and replacement of failed components, or in-flight repair.

Purpose of In-Space Maintenance

The primary reason for considering in-space maintenance of the propellant logistics module is that it may prove economical despite formidable hazards. If a tank failure occurs during the propellant transfer interval and the module can be recovered, another shuttle flight is required to top off the SB tug. This costs about ten million dollars. If the module cannot be recovered, another 2.8 million dollars is necessary to replace it for a total loss of 12.8 million dollars. This represents a maximum loss per mission. If the failure occurs after completion of propellant transfer and the module is recovered, there is no loss; but if it cannot be recovered, replacement is required at 2.8 million dollars. This represents a minimum loss per mission.

To establish a redundancy payoff, if any, for the propellant logistics module, a weight penalty of 620 pounds of redundant components was added to provide a fail operational/fail safe capability for each of the module's subsystems.

This assumes that each of the subsystems has one critical component and each of these has a reliability of .99. The reliability of the ten components operating in series without redundancy - all must function if the mission is to be completed - is .9045. This follows from Reference 9.6-1 where

$$Ps_i = e^{-\lambda T} = e^{-T/MTBF} \text{ for each component}$$

$$Ps_s = Ps_1 \times Ps_2 \times Ps_3 \ldots \text{for the total system}$$

where

P_s = probability of satisfactory performance over the time interval T

λ = failure rate

MTBF = $1/\lambda$ = mean time between failures

The use of this equation assumes a Poisson probability density function for the failure rate of the components. This is typical for electrical components after burn-in, based on laboratory life-cycle test data. Also assumed is that the individual failures are independent and do not propagate to other components. Using this equation, the system reliability is .9995 with single redundancy for each of the ten components.

Using a minimum mission success probability of $P_S = .90$, ten missions might fail out of every 100. The total program loss under this assumption could range between 28.5 and 128.5 million dollars and still meet mission success criteria. If the probability of mission success was .99, the maximum loss could be lowered to the range of 13.1 to 23.1 million dollars for 100 missions. To achieve this reliability, each of the 100 flights is penalized by the added weight (and thus reduced propellant transport capability) of the redundant components, although only ten might ultimately use them and of these, one module may still be lost. This evaluation signifies the great advantage in this case of redundancy for unscheduled maintenance in orbit. This is attributed to the low weight of the redundant equipment. The cost elements which formed the basis for this conclusion are presented in Table 9.6.1-2.

Maintenance Concepts:

There are four basic maintenance concepts - automatically switchable redundancy, manually switchable redundancy, remove and replace (R&R), and bench repair. They are described below in order of increasing equipment down-time between failures.

Automatic redundancy requires no maintenance actions by a crew. A component failure is detected and isolated by on-board equipment and the redundant component is immediately activated. Manual redundancy is similar to the automatic mode except that the backup element is formally activated by either a local or remote operator. In addition, some fault isolation instructions and hand tools may be required by the equipment designs utilizing local crew support. The remove and replace concept requires the physical removal of the failed part and its replacement by a qualified spare part. More sophisticated tools, instructions, fault isolation equipment, and crew skills are required. Bench repair involves the in-space rework of a component, either in-place or after removal from the subsystem. Highly specialized skills and equipment are required to support this concept (Reference 9.6-2).

For the ISPLS propellant tank module, the most feasible defense against in-flight failures is some form of redundancy incorporated directly into the individual subsystems. Since the weight penalties for R&R are the same as for redundancy, the latter is preferred to eliminate EVA's associated with the former. Also, the R&R payoff is greatest when a few spares can be used to back up a number of common parts, which is not the case with the logistics module. Bench repair is not justifiable on a mission as short as the module's; it is more feasible on long duration, manned missions.

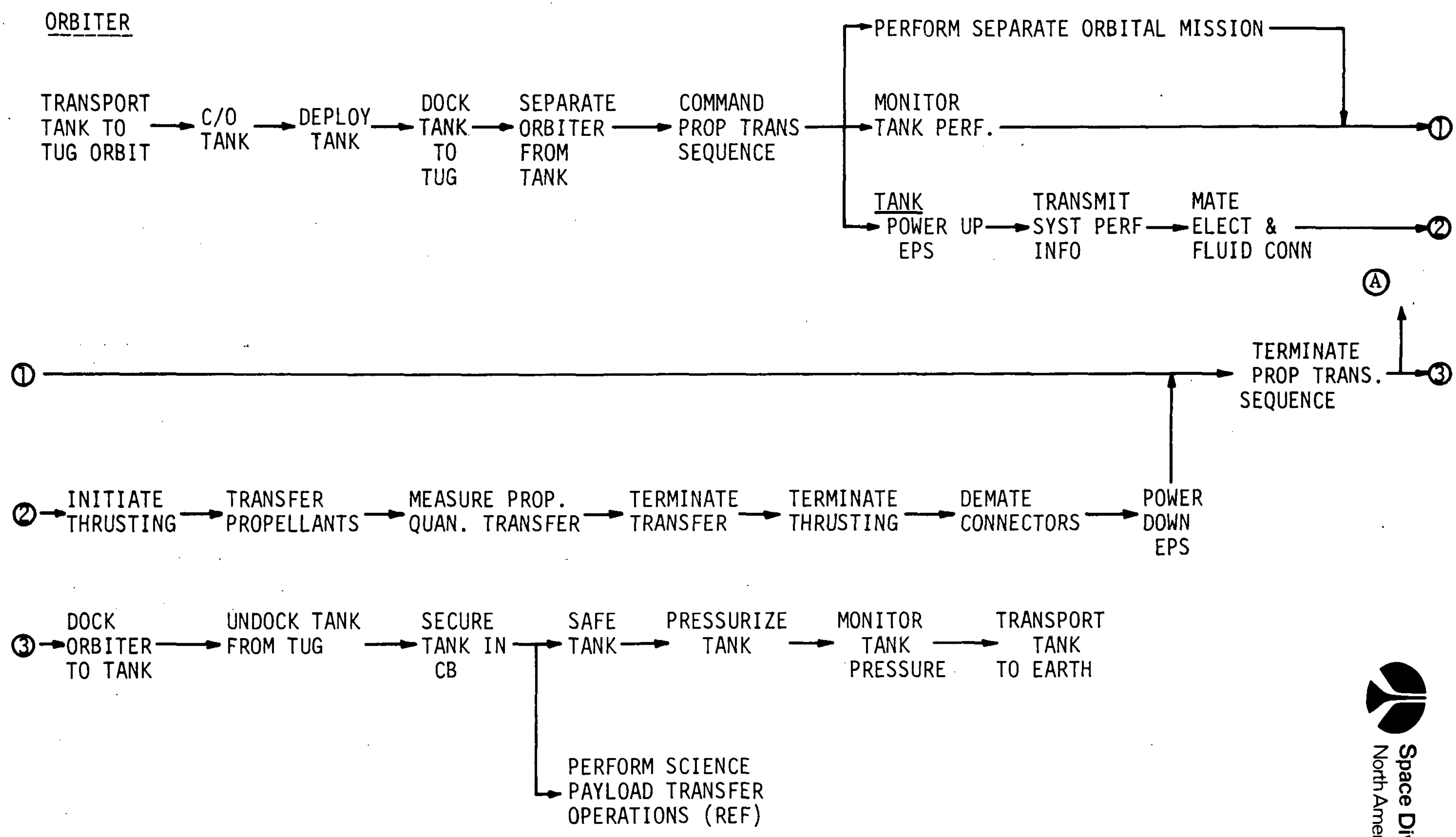
9.6.2 Optimum Location of Maintenance Tasks

Representative maintenance tasks necessary to support in-space propellant transfer operations were defined from a functional analysis of space-based tug propellant logistics operations. Figure 9.6.2-1 lists the primary propellant transfer functions. The potential maintenance tasks were developed by considering the corrective action required in the event any of the functions of Figure 9.6.2-1 cannot be performed due to a propellant module subsystem failure. Failure candidates and the subsequent corrective action functions are given in Figure 9.6.2-2. Those functions which involve unscheduled maintenance are identified. Whenever possible, unscheduled maintenance tasks will be deferred

TABLE 9.6.1-2 MAINTENANCE COST ELEMENTS(1)

Probability of Mission Success	Weight of Redundant Components (lbs)	Shuttle $/Flt	$ Per Tank	Propellant Makeup Cost Per Shuttle Flt	Min. Loss Per 100 Missions	Max. Loss Per 100 Missions
.9045	0	10	2.85	0	28.5	128.5
.9995	620	10	3.56	.054	13.1	23.1

(1) All costs in millions of dollars

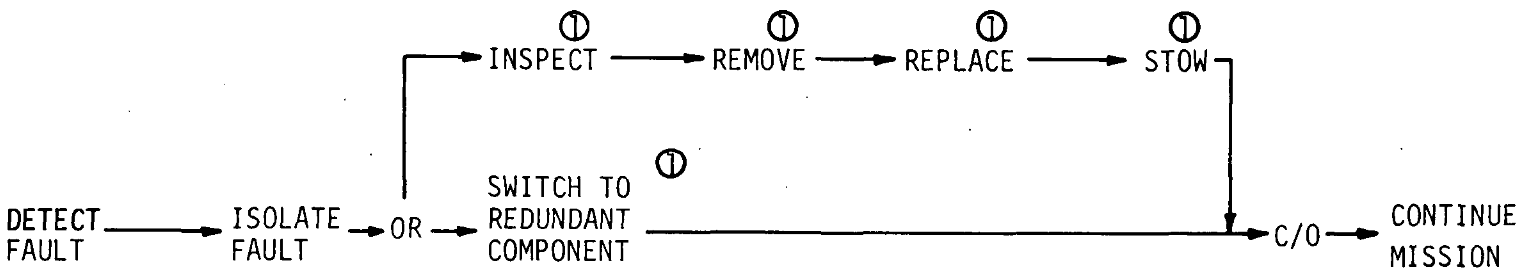


Ⓐ TANK FAILURE PRIOR TO THIS FUNCTION MEANS PROPELLANT LOGISTICS MISSION MUST BE REPEATED AND INITIAL SCIENCE PAYLOAD RETURNED TO EARTH. FAILURE AFTER THIS FUNCTION DOES NOT AFFECT PLACEMENT MISSION. IF TANK CANNOT BE RECOVERED ON FIRST MISSION SPECIAL EQUIPMENT MAY BE REQUIRED TO SECURE IT ON A FOLLOWING MISSION

Figure 9.6.2-1 Propellant Transfer Functions

SUBSYSTEM FAILURE

- PROP TRANSFER (NO TRANSFER)
- ACS (NO/INTERMITTENT/RUNAWAY JET)
- COMM (NO COMMAND CAPABILITY)
- EPS (NO POWER)
- PROP DUMP (NO DUMP CAPABILITY)
- INST (NO MONITOR CAPABILITY)



① UNSCHEDULED MAINTENANCE TASK

Figure 9.6.2-2A Propellant Transfer Subsystems, Failure Modes, and Maintenance Functions

PRESSURIZATION (CAN'T PRESSURIZE EMPTY SECURE, SAFE TANK)

DETECT FAULT → ISOLATE FAULT → 1 OPEN VENT VALVE → 1 OPEN DUMP VALVE → 1 OPEN DUAL FILL & DRAIN VALVES → MONITOR → TRANSPORT TANK

Figure 9.6.2-2B Propellant Transfer Subsystems, Failure Modes, and Maintenance Functions

ACS (PERMANENT DYNAMIC INSTABILITY - HI SPEED, MULTI-AXIS TUMBLING, TUG + TANK
PARTIAL PROP TRANSFER COMPLETED, RCS PROP EXPENDED)

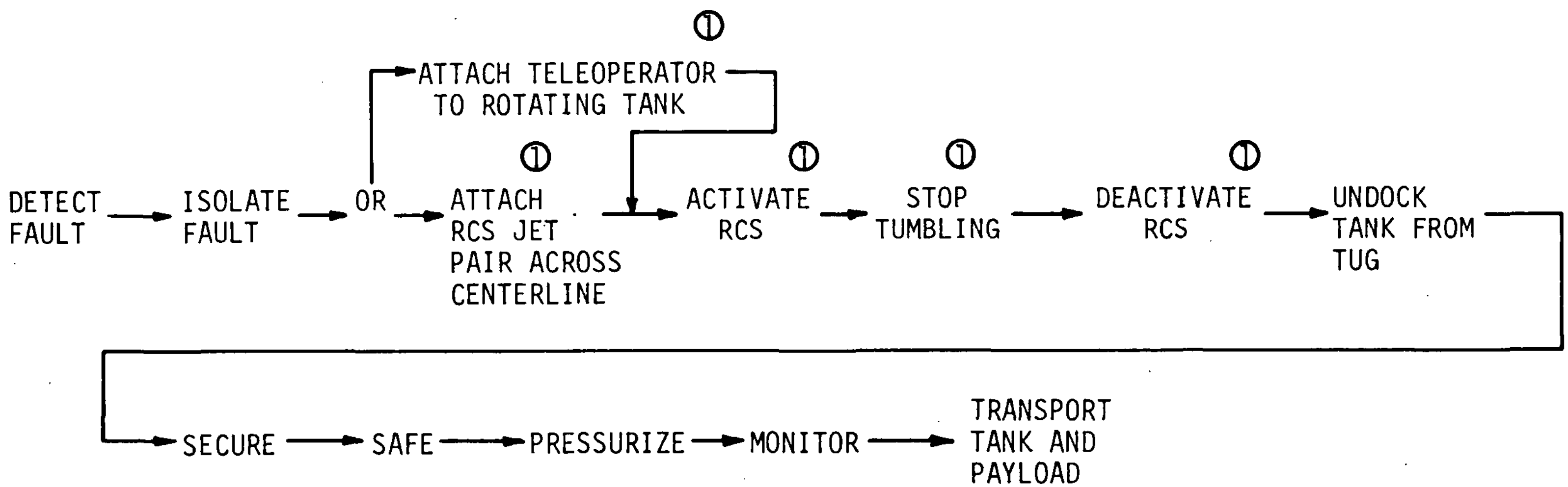


Figure 9.6.2-2C Propellant Transfer Subsystems, Failure Modes, and Maintenance Functions

DOCKING (CAN'T UNDOCK AFTER TRANSFERRING PROPELLANT)

DETECT FAULT → ISOLATE FAULT → ① ACTIVATE SECONDARY SEP SYSTEM ON SB TUG → RETRIEVE TANK & DOCKING SYS → SECURE → SAFE → PRESSURIZE

↓

MONITOR

↓

TRANSPORT TANK (PL GOES ON TUG)

DOCKING (ASSEMBLE DOCKING SYSTEM ON SB TUG)

② TRANSPORT TANK & DOCKING SYS TO SB TUG ORBIT → C/O TANK → DEPLOY TANK → ① ASSEMBLE DOCKING SYS ON SB TUG → DOCK TANK TO TUG → COMPLETE PROPELLANT TRANSFER

② DELIVERY OF SPARE SECONDARY DOCKING SYSTEM MAY BE COMBINED WITH A FOLLOWING ORBITER MISSION TO PRECLUDE A SPECIAL FLIGHT FOR THIS REPAIR.

Figure 9.6.2-2D Propellant Transfer Subsystems, Failure Modes, and Maintenance Functions

until the module has been returned to its ground maintenance facility. Unscheduled maintenance tasks which will be performed in space are limited to activation of redundant components necessary for propellant transfer and module recovery. Table 9.6.2-1 lists those subsystems essential for module recovery. No scheduled maintenance tasks are planned during space operations; all these can be done at considerably less expense on the ground. Typical scheduled maintenance tasks and their frequency are given in Table 9.6.2-2.

9.6.3 Definition of Maintenance Support Equipment

A "fail-operational and fail-safe" design philosophy was selected for the critical module subsystems to permit the mission to continue if possible and if not, at least to recover the module. For what might be considered a normal range of malfunctions and failures, therefore, no maintenance support equipment is required in space.

The possibility of a major vehicle accident or catastrophe with the module is always present, independent of the random component failures covered above. These types of events include docking collisions, fires, meteoroid penetrations, and explosions. Maintenance required in these cases would be directed toward recovery of the empty module and return to earth for failure analysis. Also, it would be desirable to remove a target of the size of the module from the high traffic density zone of propellant transfer operations, even if failure analysis was not required. The functions involved in the recovery operation are shown in Figure 9.6.3-1.

Support equipment necessary for these operations might include torches for flame cutting to fit the module inside the cargo bay, tie-down fittings and cables to secure the module and containers to store loose equipment. The space shuttle's manipulator arms could be used to position and operate the torches and cut away extended module structure which interferes with stowage in the orbiter's cargo bay. Support equipment for recovery purposes would not be carried on every shuttle flight due to the expected low use rate and weight penalties. It would be preferable for the shuttle which delivered the propellant module that subsequently became damaged to first obtain TV, motion and still pictures of the module and then return the science payload to earth. Following damage assessment from the pictures and available data, maintenance support equipment for recovery of the orbiting module could be scheduled as additional cargo on another regular shuttle placement mission whenever the full capability was not required.

The teleoperator module shown in Figure 9.6.3-2 was studied by General Electric (References 9.6-3 and 9.6-4) for remote multi-mission orbital maintenance. Its orbital life is greater than ten days. It utilizes two bilateral electric manipulators each capable of six degrees of freedom and can develop a 15-lb force and a 40-inch reach. Additional characteristics are presented in Table 9.6.3-1. For those cases where the recovery appears hazardous to the orbiter, this type of module might be capable of, for example, nulling the residual rotation of an otherwise uncontrollable module or safing and draining a full propellant tank.

TABLE 9.6.2-1 MINIMUM SUBSYSTEMS ESSENTIAL FOR MODULE RECOVERY

Subsystem	Essential Condition
Propellant Dump	Tank must be emptied prior to recovery
Docking	Tank must be separated from tug prior to recovery
Electrical Power	Propellant transfer rack must be withdrawn from tug connectors
Structure	No structural damage which would prevent tank from entering cargo bay and being secured to tie-down points
Attitude Control	Tank must remain in inertially-fixed attitude to permit orbital docking

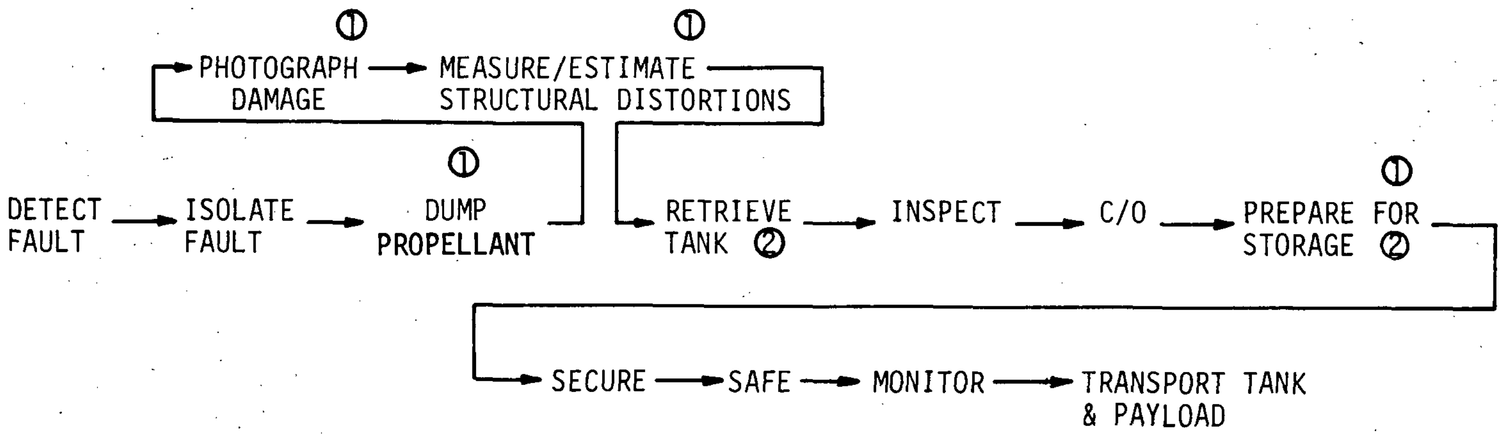
TABLE 9.6.2-2

SCHEDULED MAINTENANCE
REQUIREMENTS AND FREQUENCY

Requirement	Frequency		
	Each Flight	Each 10 Flights	Each 50 Flights
Visual Inspection	X		
Checkout	X		
Leak Check	X		
Tank Interior Inspection		X	
Replace Seals		X	
Replace Valves		X	
Replace Bellowed Lines		X	
Replace Disconnects		X	
Major Tank Inspection			X
Proof Pressure Check			X

MAJOR DAMAGE

- FIRE/EXPLOSION
- METEOROID IMPACT
- COLLISION



① UNSCHEDULED MAINTENANCE TASK

② SECOND FLIGHT MAY BE REQUIRED TO ACCOMPLISH THIS. RECOVERY EQUIPMENT MAY BE COMBINED WITH ANOTHER ORBITER FLIGHT TO PRECLUDE SPECIAL RECOVERY FLIGHT

Figure 9.6.3-1 Major Damage Modes and Recovery Functions

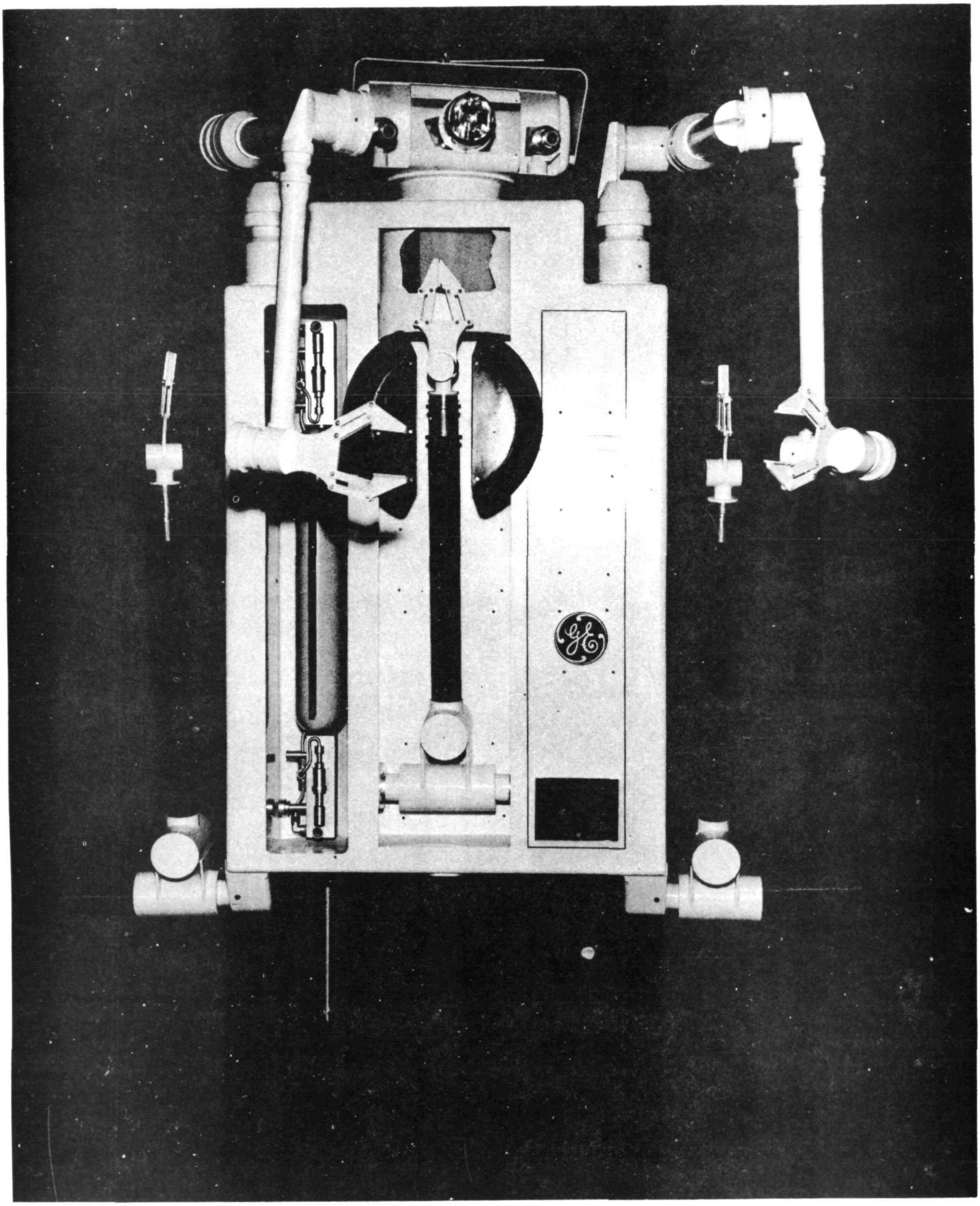


Figure 9.6.3-2 General Electric Multimission Remote Unit Concept (Ref 9.6-3)

TABLE 9.6.3-1 (REFERENCE 9.6-5)

RMU WITH MANIPULATOR SYSTEM
WEIGHT AND POWER SUMMARY

Subsystem	Power Watts	Weight Lbs
Video	33.0	52.0
Propulsion	25.0	22.0
Guidance and Control	83.9	56.8
Communications	21.8	28.9
Power	-	165.0
Thermal Control	-	5.0
Manipulators (two)	40.0	81.0
Docking Tethers (three)	nil	50.0
Structure	-	95.0
Harnessing	-	45.0
TOTAL	203.7	600.7

9.6.4 List of Spare Parts for Orbital Replacement

No spares are required for orbital replacement of parts on the logistics module or support equipment. All requirements for spares have been incorporated as redundant equipment directly on the module. The principal payoff with space spares occurs when commonality exists among the operating components and the spare can be used as backup for any of the components which fail. Also, the spares concept is effective if the parts are small, lightweight, and easy to install.

In the case of the propellant logistics module, there is no incentive to provide spares on-board the module or in the orbiter since they are both charged against the payload. While the spares would weigh somewhat less than the redundant installation, this can be offset by the increased complexity and hazards of utilizing remote teleoperators or EVA to remove and replace the faulty equipment. From these considerations, the module was designed with sufficient redundancy to eliminate the need for teleoperators and EVA and the need for orbital spares except possibly in the case of some accidents or catastrophes.

9.6.5 Determination of Maintenance Influence on Logistics Concepts and Orbital Operations

The scope of orbital maintenance operations depends primarily on the complexity of the space vehicle's design and the duration of its mission. Long, complex missions require more maintenance than short, simple ones to achieve the same mission success. The propellant transfer mission is short and the logistics module design is relatively simple, therefore, minimal maintenance is planned and this will be accomplished through redundancy. In this case and probably for the majority of space missions, maintenance has relatively little, if any, influence on logistics concepts and orbital operations. The primary influence of maintenance will be in the design and layout of the vehicle's subsystems, ground support equipment, and facilities.

The requirements and criteria for a maintainable module design are presented in Appendix C. These ideas have been incorporated in the module's design. They are based on NR's aircraft, Apollo, and S-II operations experience and information from Reference 9.6-6.

9.7 THE ROLE OF MAN IN ORBITAL PROPELLANT LOGISTICS

The need for man in space is greatest when the tasks to be performed are problems involving the rapid and simultaneous assessment of several parameters and the initiation of a corrective reaction which is selected from several alternative methods in a non-lethal environment. Simple, repetitive, long duration, hazardous, predictable tasks are the domain of the machine. The orbital propellant transfer operation is simple, repetitive, and potentially hazardous. For these reasons the transfer operation has been almost totally automated.

The other portions of the logistics mission such as tank module delivery, rendezvous, module deployment, docking, undocking, separation, stowage, and return to earth are performed by orbiter subsystems operated and controlled by the orbiter crew. None of these tasks are peculiar to propellant transfer missions.

9.7.1 Functional Orbit Logistics Model

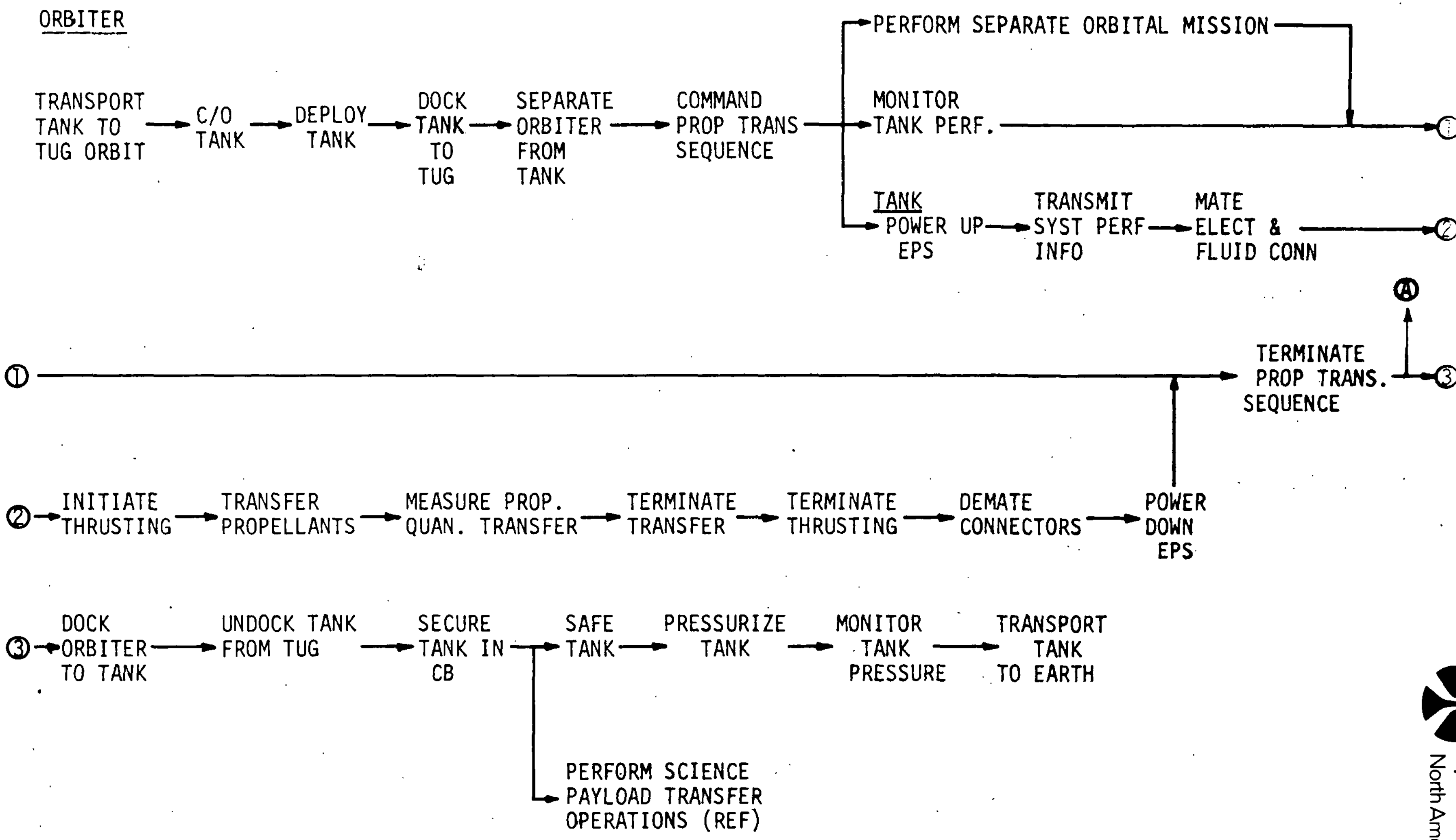
A functional model of the nominal propellant logistics mission is given in Figure 9.7.1-1 which was presented earlier as Figure 9.6.2-1. All of the orbital functions are performed under the control of the orbiter crew. The propellant transfer functions satisfy the criteria for machine implementation and have been developed with this in mind. For those missions which involve aborts, accidents, or catastrophies, the role of man would probably be expanded greatly depending largely on the circumstances of the particular event. Here man could be employed to assist in recovery and safing of the propellant logistics module for subsequent failure analysis.

9.7.2 Criteria for Man Versus Machine Cost Effectiveness

The consideration of whether to use a man or a machine for a propellant transfer task depends primarily on the complexity of the task and the hazards of the environment. The mechanics of ground-based cryogenic propellant transfer are not complex and considerable experience has been acquired in the last 10 years. However, there is virtually no experience with in-space propellant transfer between tanks. The ground environment has always been recognized as hazardous but personnel have been allowed to work under fully-fueled vehicles after observing extraordinary safety requirements. NR Red crews have performed such maintenance tasks under loaded S-II stages on 12 out of 15 vehicles in acceptance tests at the Mississippi Test Facility. On each of these occasions, one to three visits were necessary by the crew. In each case detanking was avoided and the test was completed without recycling. Some of the requirements and procedures necessary for Red crew operations are given in Appendix D. They have evolved over several years experience with propellants and can provide a guide to initial manned orbital procedures around cryogenic vehicles.

In-space work experience to date indicates that man may be able to perform maintenance tasks for about six hours per day. The buddy system would be employed for all EVA operations and both could work simultaneously. If more than 12 manhours per day are required, additional crewmen would have to be available otherwise the work will take longer to complete.

An alternative to manned EVA operations is the use of manned maintenance modules or completely remote teleoperators. Maintenance modules have been described in some studies, such as Ref. 9.7-1, to support maintenance operations. Three generic classes have been designed - teleoperators operated by man within a shirtsleeve environment such as those provided on the orbiter, the open work platform, and the astronaut maneuvering unit. These concepts are shown in Figures 9.7.2-1, -2 and -3, respectively. Performance capabilities for the shirtsleeve and crew concepts are given in Tables 9.7.2-1 and -2. The maneuvering unit, from Ref. 9.7-1, is a small back pack with propulsion, auto-



Ⓐ TANK FAILURE PRIOR TO THIS FUNCTION MEANS PROPELLANT LOGISTICS MISSION MUST BE REPEATED AND INITIAL SCIENCE PAYLOAD RETURNED TO EARTH. FAILURE AFTER THIS FUNCTION DOES NOT AFFECT PLACEMENT MISSION. IF TANK CANNOT BE RECOVERED ON FIRST MISSION SPECIAL EQUIPMENT MAY BE REQUIRED TO SECURE IT ON A FOLLOWING MISSION

Figure 9.7.1-1 Propellant Transfer Functions

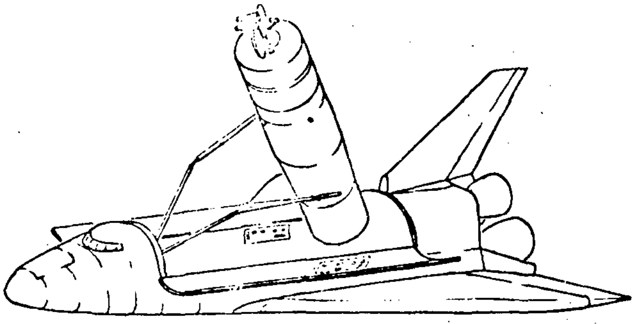


Figure 9.7.2-1 Orbiter Manipulators

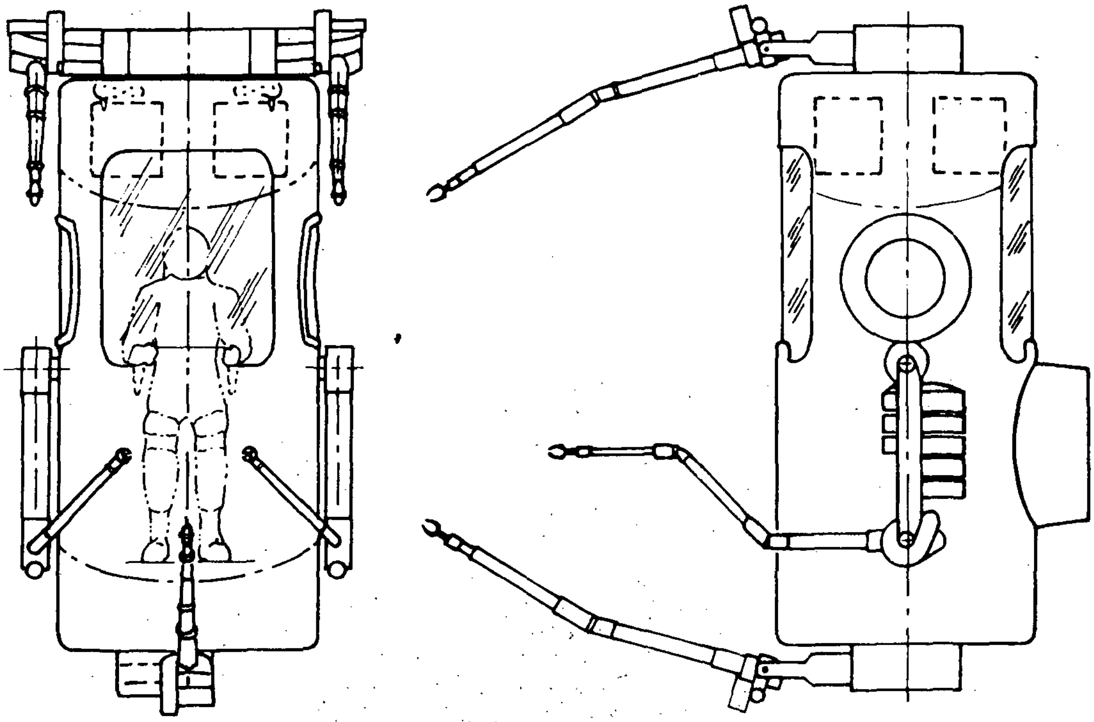


Figure 9.7.2-2 The Ling-Temco-Vought Space Taxi (Ref. 9.7-1)

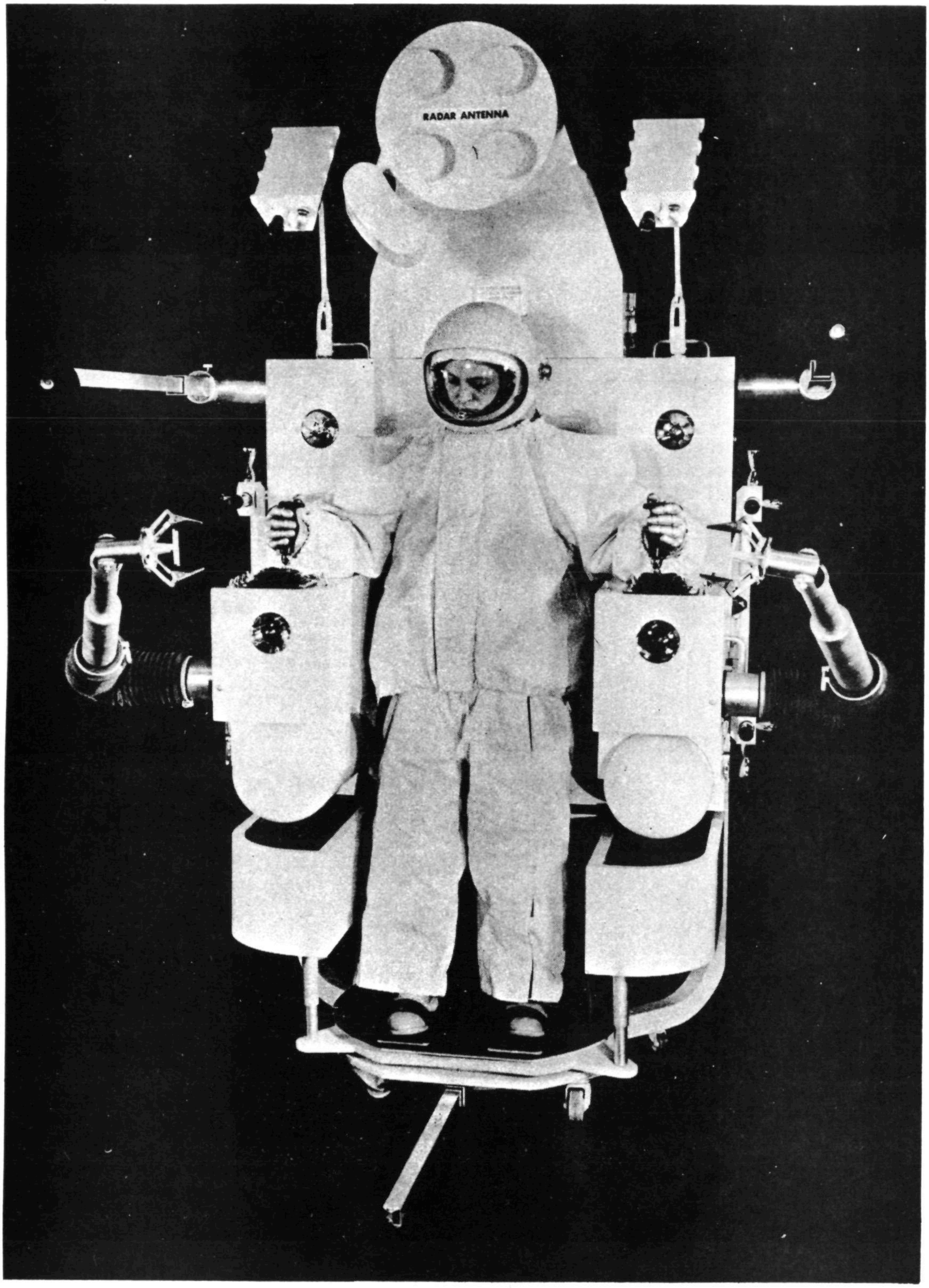


Figure 9.7.2-3 Astronaut in Bendix EVA Work Platform (Ref. 9.7-2)

Table 9.7.2-1 Ling-Temco-Vought Space Taxi Manipulator Arms Characteristics

Maximum force at slave "hands" (each manipulator)	25 lb
Maximum force at master handle (each manipulator)	12.5 lb
Force boost ratio between master and slave	2:1
Maximum master-slave velocity (at slave hands)	30 in./sec
Maximum force at slave "hands" while indexing (each manipulator)	12.5 lb
Maximum indexing velocity (at slave hands)	10 in./sec
Total Weight	3473 lbs
Work Cycle	8 hrs

Table 9.7.2-2 Bendix Work Platform - Manipulator Characteristics

Electrically driven	
Force amplification	2:1
Maximum force at the slave	25 lb
Maximum force at the master	12.5 lb
Working volume at master	1 ft^3
Working volume at slave	$\sim$525 ft^3 (sphere of 5-ft radius)
Total Weight (incl. man and propellant)	1500 lbs
Work Cycle	4 hrs

matic stabilization, life support, tool kit, environmental control, and communications subsystems. A full-pressure suit design is assumed which permits complete wrist, hand, and finger dexterity.

An example of a remote teleoperator was presented earlier in Section 9.6.3. All of these devices extend the capabilities of man - either his environment, reach, force, or torque - at the price of a great increase in task times. This increase has been defined as the hindrance factor, the ratio of estimated/simulated space task time to earth task time. For the concepts described above, these hindrance factors range from 3 to 10. This increased task time is due primarily to operating differences between the human arm-hand which has 35 degrees of freedom and a "good" master-slave teleoperator which has force and motion feedback and seven degrees of freedom - three translation and rotation and one gripping action. Other factors which influence the hindrance factor are lighting, teleoperator design, and lack of depth perception in the visual presentation.

It therefore appears that either man and/or machine is capable of performing propellant transfer in space provided the module design incorporates features which support the selected mode such as "remove and replace" compatible hardware, hand holds, and teleoperator attach points. The costs of either concept would be equivalent (Ref. 9.7-3). The costs for man in space can range from $12,500/hr for eight men delivered by the shuttle who work six hours per day for 30 days to $1,500,000/hr for two specialists working one shift. The major cost is in transporting the man or machine into space and return, and this would be the same for man or machine. The equipment development and production costs would tend to offset each other with the higher development and lower production costs (due to greater reuse) of the teleoperator and the lower development but higher production costs of space suits and back packs (many suits required coupled with low reuse).

9.7.3 Extent of Man's Role

The role of man is fundamentally presumed in all orbiter and orbiter-related functions associated with the propellant logistics missions. These functions include all those labeled "orbiter" in Figure 9.7.1-1. The extent of man's role here is not analyzed in detail because those functions are required for all shuttle missions and are not propellant-peculiar. The unique propellant functions are labeled "tank" in the figure, and, contrary to the orbiter functions, require no role for man except to monitor essential measurements such as tank pressures, flow rates, valve positions, and power levels. This can be done either by the orbiter crew and/or personnel on the ground.

The functions shown in Figure 9.7.1-1 are for a normal mission; that is, a mission without any failures which prevent completing the logistics mission successfully. The role of man is sensitive to mission success; if a failure occurs, the role of man escalates. In-space collisions, meteoroid puncture, catastrophic failures, fires, and explosions involving the module may require recovery of the module or its removal as an orbital traffic hazard. Either recovery or removal will require capture of the module, insertion in the orbiter cargo bay, securing it to the attach points, safing pressurized tanks, and deorbiting.

Should the module's configuration be deformed as a result of the above accidents, man's role may require utilization of the orbiter's manipulators, EVA, or control of a remote teleoperator. Which of these modes would be used depends on the tasks and hazards involved in the recovery. However, because the frequency of use of a teleoperator would be expected to be quite small for propellant logistics recovery missions, it cannot be justified economically based on these missions alone.

The above conclusions apply primarily to space-based tug and CIS propellant logistics missions. For the RNS, the conclusions are valid provided all manned operations are conducted within the shielded radiation environment forward of the nuclear reactor. Full shirtsleeve operations are permissible in the direct vicinity of the logistics module - RNS forward skirt area following engine shutdown at a dose rate which will not exceed .5 rads/hr, an acceptable rate for technicians on occasional visits of relatively short duration.

9.7.4 Crew Capability, Skills, and Training Requirements

The tasks identified in the previous section can be divided into two principal classes - those which are repeated on almost every orbiter flight such as rendezvous, deployment, activation, checkout, docking and recovery of payloads and orbital maneuvers, and those peculiar to propellant logistics. Crew requirements for the first class will be defined to satisfy orbiter mission requirements and will not be treated here.

Propellant-transfer peculiar requirements are based on manned support to manipulator deployment, docking, undocking, and recovery of the module, to monitoring propellant transfer instrumentation readouts, and to module recovery operations following a catastrophic tank failure. The latter task may entail either EVA, orbiter, manipulator, remote teleoperator or all of these actions simultaneously depending on the extent of the failure; for example, failures which involve a severely damaged module which cannot be undocked from an undamaged tug, CIS, or RNS.

Propellant transfer tasks can be further subdivided into those which are routine and those which are not. Routine jobs such as those associated with every propellant transfer mission can and should be performed by the orbiter crew. No special new skills or training requirements would be necessary since typical tasks such as instrument readout and interpretation and module deployment - although one with potential sloshing modes - are nearly identical with other tasks which they will normally perform with science payload and tug deployment missions. Non-routine propellant transfer tasks, however, are best performed by special teams - such as the Apollo-Saturn Red crews which have been selected and trained for specific recovery missions. Red crew personnel would have a thorough understanding of the subsystems and operations of the particular vehicle such as tug, CIS, RNS, or propellant module which they normally service on the ground. They would also be skilled in orbital maintenance and temporary repair - including operation of remote teleoperators. These teams would be expected to operate on both empty vehicles and vehicles with cryogenic propellants aboard. These points are summarized in Table 9.7.4-1.

Table 9.7.4-1 Proposed Manned Task Assignments

Propellant Logistics Tasks			Responsibility	
Normal Orbiter Missions	Propellant Missions	Recovery Missions	Orbiter Crew	Red Crew
Rendezvous			X	
Payload (1) Deployment			X	
Activation (1)			X	
Checkout (1)			X	
Docking (1)			X	
Undocking (1)			X	
Recovery (1)			X	
Orbital Maneuvers			X	
	Tank Checkout		X	
	Tank Deployment		X	
	Tank Docking		X	
	Tank Recovery		X	
	Transfer Monitoring		X	
		Orbiter Manipulators	X	
		Teleoperator		X
		Flame Cutting/Welding		X
		Assembly/Disassembly		X
		Securing		X
(1) Science Payload				

9.7.5 Sensitivity of Man's Role to Program and Logistics Concept Changes

The role of man in propellant logistics missions has been found to be essential during the delivery and mating of the propellant logistics module to the using vehicle and the subsequent recovery of the module. This has evolved from the knowledge that man will be aboard the orbiter and will be available to perform these tasks. The actual propellant flow process only requires man for backup and support roles primarily because the operation is simple and hazardous.

These conclusions are independent of the mode of propellant transfer, i.e., linear acceleration, rotational acceleration, capillary devices, or modular tank exchange, since all are relatively simple and hazardous. They are also valid for each of the potential using vehicles such as the tug, CIS, or RNS except that certain precautions, described earlier, must be observed. For change in program level of activity, for example, progressing from Program Level E through Program Level A, there is no need to change the role of man. Here there are only reductions in the types and number of placement missions but the individual missions are all similar. The role of man is also unaffected by the configuration of the payload placement stage; that is, whether it is space-based or ground-based. In the examples previously given, primary attention was directed towards the space-based tug by the basic nature of this study. By using a ground-based tug, Centaur, Agena, or FW-4S as during 1979-1990 in Program Level A or during 1979-1984 in Program Levels B through E, no in-space propellant transfer is required. However, since this process had been automated in this study, the role of man is not affected. Utilization of ground-based vehicles does not eliminate the need for Red crews since their capabilities can also be applied to the recovery of ground or space-based tugs.

Although not related to propellant transfer, there is one operation which very probably will expand the role of man in space. In Program Levels A through E, some of the planetary and lunar missions with large payloads require tandem payload propulsive stages. Some payloads exceed the shuttle's capability; and additional stages and payloads must be brought up on separate shuttle flights. These multiple stages and payload segments must be assembled in space prior to departure. This assembly and the subsequent checkout will undoubtedly require manned guidance and control.

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10.0 PROPELLANT LOGISTICS INTERFACE DEPENDENCIES

A large scale propellant logistics capability is required for operation of a space-based tug, a CIS, or an RNS. It may also be desirable for use in conjunction with a ground-based tug for special missions or for added flexibility.

A cost effective propellant logistics capability, as established as a result of this study, would consist of a large logistics propellant module (tank) approximately 15-ft diameter x 38 ft long to be carried to orbit by the shuttle. Propellant would be transferred to the user vehicle by deploying the tank from the shuttle cargo bay, attaching the tank to the user vehicle, removing the tank from the shuttle, and then conducting the propellant transfer operation.

The analysis of the interfaces envolved in the propellant logistics concept indicates no major problem areas. However, there are interdependencies that must be recognized in the early design phases of the various elements and the necessary guidelines defined to insure operational compatibility. Relevant interface considerations with recommendations regarding areas for further coordination and study are presented below.

10.1 ORBITER CAPABILITIES

The orbiter configuration, as baselined for this study (original 161C baseline and updated configurations), has a 15 ft diameter x 60 ft long cargo envelope and the capability to carry 65,000 lbs to an easterly launch earth orbit. Provisions are also made for the orbiter to support its cargo in the areas of monitoring, data management, communications and power supply. The orbiter configurations include manipulator arms for the deployment (and restowing) of its cargo and to assist in the docking of cargo to space-based vehicles. The orbiter can support logistic operations with its three-man crew for nominal mission durations of up to seven days. These are the broad aspects of orbiter capabilities that were considered in the conceptual definition of propellant logistic operations and module design.

a. Tug - The logistic operation for propellant delivery to the tug is based on a payload sharing concept where the payload and the propellant required for its placement mission are delivered on the same flight. This is operationally efficient since the majority of the scientific payloads defined for the various program levels are relatively small and light-weight and the tank module size permits use of almost 1/3 of the bay for such cargo. In only very few cases is the payload size or the mission propellant requirement too great for a single shuttle flight to support the mission. Due to the low weight of most of the payloads (only a few hundred pounds) there is little penalty in designing the logistic tank module to account for the entire 65,000 pound shuttle capacity when full. The reduced loading of the tanks to allow for payload weight is insignificant, and the same tank module can be used when propellant only flights are required. The effects of possible payload capability reduction in future orbiter configurations are discussed in Section 8.0.

b. CIS - For propellant logistics operational support to the CIS, 19 shuttle flights are required for one filling, thus the tank module is designed

for the full shuttle capability. Due to the requirement for additional LH_2 to make up for boiloff during the prolonged filling process, the hydrogen tank and thus the modules are slightly longer than the similar logistic modules for the tug. Since the operational mode is not based on payload sharing the longer module is consistent with the orbiter cargo volume capability.

c. RNS - The RNS main engine propellant is hydrogen and the volume limitation of the cargo bay is such that only about half the 65,000 lb weight capability can be utilized in delivering an all hydrogen load. The essentially all-hydrogen tank module (a small amount of LOX would be delivered for RNS attitude control and fuel cells) would fill the orbiter cargo bay. The module is 3 to 4 feet shorter than the bay due to the swing-out ring and deployment requirements. The LH_2 tank is enough shorter to allow for the line interconnect fixtures and equipment in the logistic module. This tank size would hold approximately 29,000 lb of LH_2 for delivery to the RNS on each flight.

10.2 ORBITER INTERFACE

Discussion of logistic module and orbiter relationships and the interface considerations are given here; more detailed interface definition is contained in section 9.0 and in the logistic module inboard profile drawing. The location and orientation of a tug supportive logistic module in the orbiter cargo bay are based on several interrelated considerations.

Figure 4.1.1-2 shows considerations of cargo c.g. location. The orbiter imposes two restrictions on its cargo for the return phase of the mission. First, the total cargo weight must be below 40,000 pounds and second, the combined c.g. of all cargo must fall within a limited range. For ascent or orbital phase of the delivery, the c.g. location is not constrained, but for aerodynamic control of the orbiter during entry and suborbital glide the c.g. must fall within a limited location band. The figure shows the entry c.g. limits to be a function of cargo weight. For normal operations the logistic tank module will be empty on return and the c.g. of the 4,000 to 5,000 pound module can be anywhere in the forward 42 feet of the cargo bay. For an abort case the propellant is dumped from the logistic tanks to bring the total cargo weight down to the 40,000 pound landing limit imposed by orbiter structural limitations. A tank located in the forward end of the bay would necessitate dumping additional propellant to bring the c.g. within the required limit.

Two alternative locations in the cargo bay are shown for a typical 38-foot long, transfer capability, propellant logistic tank module. Whether the module is forward or aft in the bay, the module is oriented so that the LOX tank is toward the center of the bay to facilitate c.g. control. A tank located forward in the bay could have the LOX tank forward, which would require the dumping of slightly more propellant than for the orientation shown. Other tank configurations such as without the inverted LH_2 tank bulkhead or with the propellant transfer interface on the opposite end would have correspondingly different c.g. locations. No allowance for a payload which may be sharing the cargo bay has been made in these c.g. locations. Most payloads are relatively light-weight and the combined c.g. will shift toward the payload to a more favorable position.

The c.g. envelopes on Figure 4.1.1-2 show the approximate locations of the tank module c.g. as propellant is dumped. The c.g. can range across the band depending on whether the remaining propellant is settled to the forward or the aft end of the tank or in between. The cross-hatched envelope shows the c.g. range if both LOX and LH_2 are dumped. The shaded envelope is for dumping LOX only. Dumping LOX only will satisfy the c.g. location and weight reduction requirements and may be preferable to dumping both propellants. A single dump system would suffice and the hazards of dumping LH_2 would be eliminated.

Additional considerations in locating the tank module in the cargo bay include payload sharing and deployment. The module should be located to allow maximum remaining cargo bay volume for payload sharing. Deployment of both the logistic tank module and the payload must be planned when choosing tank location. Any swing-out deployment or stabilization fixtures and the cargo bay umbilical interface will influence tank module location. Possible reach limitations of the manipulator arms are a consideration for payloads that are stowed in the extreme aft end of the cargo bay.

Propellant settling orientation in the tanks is another important factor. If possible, the tank is oriented so that propellant will settle toward the same ends of the tanks when they are filled on the pad as when they are settled by artificial g in orbital transfer. However, a currently assumed swing-out deployment dictates that the free end of the tank be where the user vehicle docks, and thus at the propellant transfer interface. In turn, an assumed docking to the forward end of the user and a linear settling mode for propellant transfer results in propellants settling toward the user docking end of the module (since the user would be accelerated forward to provide normal settling toward the aft end of its own tanks). Thus a tank module in the forward end of the bay, with a swing-out ring at the forward bulkhead, would be settled toward the user docking end both on the ground and during transfer. The tank module in the bay aft end with an aft bulkhead swing-out ring will be settled to the opposite end on the ground as during transfer. The tank module with opposite settling will have additional lines and valves to provide fill and vent capability at both ends of the two tanks.

A further consideration of tank location is the line interfaces with the orbiter. Tank draining on the pad establishes a requirement that the drain lines have no up-hill runs or liquid traps. This dictates that the line interfaces with the orbiter be made at the aft (with respect to orbiter orientation) end of the tank. Therefore, a tank in the forward part of the cargo bay requires a longer umbilical which can be traded against the added lines and valves to provide for the "opposite" settling of a module located aft in the bay.

Review of all factors associated with forward or aft stowage of the logistics module in the cargo bay has revealed no strong drivers and continued study as designs evolve will be required. Aft stowage was tentatively selected as baseline, primarily on the basis that module manipulation and spacecraft docking are more easily facilitated, to permit further studies to proceed.

10.3 DEPLOYMENT

Deployment of the logistic module and its docking to a user vehicle might be assumed to be a lesser influence on the module and cargo bay interface; but a more detailed examination shows otherwise. The deployment and docking requirements include: movement out of the bay to a position compatible with docking; physical support of the module in that position during docking; power supply, monitoring and control of the module by the orbiter until after docking and connection of lines to the user; and release of the module from orbiter physical and functional connections. Requirements for acquisition and restowing of the module in the cargo bay repeat these operations in reverse order, including the reconnection of lines with the cargo bay umbilical. The proposed concepts of meeting these requirements are outlined below.

10.3.1 Manipulator Arm Capabilities

The shuttle orbiter design requirements include that provisions be made for deploying its cargo. The current orbiter proposal (NR) includes two 50-foot manipulator arms for this purpose. Manipulator arm capabilities are summarized in Figure 4.1.1-3. In normal operation the orbiter first docks to the receiver vehicle (this could be a manipulator assisted docking where the arm from the nearby orbiter grasps the receiver and draws the two together). Then the arm grasps the cargo, removes it from the bay and docks it to the receiver. Manipulator dockings are accomplished with one or the other element attached to the orbiter (other than by the manipulator) and only one element controlled and moved by the arm. The handling of a payload (by the manipulator) to a stationkeeping receiver is not presently considered a viable mode. One arm is used to grasp the movable element (at a suitably provided manipulator interface fitting) and control the element through a programmed movement. The second arm provides redundancy; it may also be used to position a floodlight and TV to provide visual monitoring of an operation.

Figure 4.1.1-3 shows the reach envelope to be less than the fully extended arm length; approximately 40 ft. If the mode of deploying and docking a logistic module (or even a payload) to the user is assumed to take place after first docking the user to the orbiter, the docked vehicles must be in such an orientation that the arm could place the module on the forward docking port of the user vehicle. This would preclude docking the aft end of a user to the orbiter forward docking port for this purpose, as the user forward port would then be out of reach. Similarly, the logistic module could not be deployed and docked with one end at the orbiter port, since the manipulator could not reach a user that was stationkeeping another 10 to 20 feet away to draw it to a docking with the module. Thus manipulator arms, in the assumed normal operating modes do not offer a complete and simple solution to logistic module deployment and docking.

At the time of this definition, the proposed arm length and limited joint articulation indicates the manipulator could not reach to within the extreme forward or aft quarters of the cargo bay. For the payload sharing concept of propellant delivery to a space-based tug, an independently attached and deployed payload would be located in one end of the cargo bay. This interface consideration requires continuing coordination to achieve a compatible design.

10.3.2 Swing-Out Ring

A swing-out deployment ring is included in the concept of the logistic module deployment and docking mode. The ring aids in deploying the module and supports it in the deployed position so that a manipulator arm can be utilized to grasp and move the user to a docking with the module. With the ring at the aft bulkhead of the cargo bay, the deployed free end of the tank module is within reach for the manipulator arm to acquire the user at a reasonable stationkeeping distance and accomplish the docking. Utilization of the manipulator arms to accomplish a "soft" docking (rather than assuming a "fly-in" docking) will reduce the docking fixture attenuation requirements and reduce the loads in the module support and backup structure in the orbiter. The swing-out ring also assures controlled deployment of the module out of and back into the cargo bay. In returning the module to its position in the cargo bay the swing-out ring will also help align and simplify the re-engagement of the cargo bay line interconnects.

The swing-out ring will incorporate a docking system between itself and the module which will allow detachment and reattachment of the module. When deployed, the ring will be sufficiently remote from the confines of orbiter structure to allow a manipulator assisted docking. This will require less critical control (handling) requirements than for returning the module to the bay with the manipulator arm and guide rails of the orbiter deployment system. The swing-out ring will be used for zero-g deployment only and will not be a part of a structural (load carrying) interface with the orbiter.

Because the movement of the ring end of the module is slight and well controlled, use of the ring also allows the continued monitoring, control and power supply support of the module during docking. Since the active interconnect for transfer lines is on the logistic module, the power supply and commands for actuating the interconnect must come either from on-board the module or from support provided by the orbiter. Use of the swing-out ring means that the electrical umbilicals, which are easy to flex during the 30° to 40° of rotational deployment, can remain attached to the module.

10.4 INTEGRATION WITH SHUTTLE ORBITER SYSTEMS

The shuttle orbiter systems are required to accommodate the tug vehicle requirements which are similar to the logistic module requirements. Therefore, integration of the logistic module systems with the orbiter involves, in large degree, adapting to the preliminary design concepts for the tug. Commonality areas are mounting structure; swing-out fixtures; deployment mechanisms; fill, drain, dump, and vent line interfaces; and power, data, and control interfaces.

Several line and electrical interconnections are required across the orbiter to logistics module interface. The interface schematic presented in Section 9.0 shows 9 fluid lines and 3 electrical bundles across the interface (not including redundancy) and most of the lines serve more than one function. Many of the functions are strictly for pre-launch (GSE) servicing on the pad. It is assumed that the GSE connections will be made at a service panel on the orbiter (aft fuselage) and that lines in the orbiter will connect that panel

with a cargo service panel inside the cargo bay. The various cargos would then provide an umbilical to interface at the cargo service panel. In the case of the logistic module, the other end of the cargo umbilical would provide the line interconnects that could be remotely re-engaged when the module returns to the cargo bay in orbit. Since the orbiter also requires GSE connections for prelaunch fill, drain, and vent of LOX and LH_2 for its own main propulsion tanks, the systems can be integrated. Fill and drain lines for logistic module service can tee off orbiter lines. This will not adversely affect orbiter systems in supporting an occasional cargo; the number of logistic flights to support any space-based vehicle is appreciable, and in addition there would be similar servicing requirements for ground-based vehicles to be fueled in the cargo bay before launch.

Integration of additional logistic module systems with orbiter systems is indicated. The monitoring, command and control and power supply requirements were noted. It is assumed that these requirements are typical of those for many shuttle cargos and are already anticipated in the basic orbiter design. The fluid interfaces required during flight will also require integration with orbiter systems. The logistic module will require propellant dump provisions for an orbiter abort mode. The same lines that are used for fill and drain can be used for dump, and with proper integration with orbiter systems, the logistic tank propellant could be dumped (burned) through the main engines as is done with the orbiter (drop tank) propellant. Logistic tank vents must be maintained during flight and can be considered for integration into orbiter hazardous gas venting provisions.

10.5 INTEGRATION WITH USER VEHICLE SYSTEMS

The details of the interfaces between the logistics modules and the tug, CIS, and RNS user vehicles were presented in the foregoing sections of this report. With selection of the linear propellant transfer concept, the major interface considerations among the space vehicle elements are reduced to a manageable number. The following summarizes in general terms the important interfaces which must be monitored and defined as the designs evolve.

A propellant transfer and an ullage vent return line is installed for each propellant leading to a fluid interface with the logistic module. A vapor phase pump is provided in the logistic module sized to total closed loop fluid circuit characteristics. The logistic module depends on the user vehicle systems for electrical power, attitude control, data management, and communications. The settling propulsion systems are mounted on the logistic modules to allow for ground maintenance. However, control of the thrusters is provided by the user vehicle through an electrical interface. The docking system must be compatible between each user and its logistic module. Provisions are incorporated in the user vehicles for zero gravity propellant feed to the reaction control systems and to the power generation systems. To implement the self-storage concept, these vehicles must incorporate a zero gravity propellant thermodynamic control system to offset a continuous radiation heat flux and to avoid unacceptable increases in propellant temperature and tank pressure.

The final configurations of the user vehicles and the logistic module will evolve from the detail definition of the above interfaces together with a continuing coordinated design effort.

APPENDIX A

PLANNING OPTIONS ADDED AT PROGRAM LEVELS D AND E

This section reports on the development of data with which to describe the program options which were added to the NASA baseline mission program, level "C" to produce the broader mission programs at levels "D" and "E". The additions are:

- °Additional non-NASA communications satellite missions and a Saturn orbiter
- °An automated lunar program which utilizes a space tug or expendable stages for translunar injection
- °A manned lunar program which requires either an RNS or CIS for transportation of payloads between earth and lunar parking orbits
- °An illustrative augmented planetary program in which the RNS or alternately the CIS is used for trans-planetary injection of heavy payloads.

NON-NASA COMMUNICATIONS SATELLITE MISSIONS AND SATURN ORBITER ADDITIONS

Subsequent to the first ISPLS Performance Review, 97 satellite placement missions were added to Program Levels "D" and "E" per NASA Reference A-1 request. The additional missions are divided among the following categories:

- °Mission No. 78-2, General Communications Satellites. Forty-eight placements scheduled at a launch rate of four per year.
- °Mission No. 78-3, Individual Reception Broadcast Satellites. Twenty-four placements scheduled at a launch rate of two per year.
- °Mission No. 78-4, Community Reception Broadcast Satellites. Twenty-four placements scheduled at a launch rate of two per year.
- °Mission No. 60-3, Saturn Orbiter. A single placement scheduled for launch in 1989.

Orbit definition, payload weight and size, and delta-V requirements for these missions are shown in the Space Traffic Model Data of Section 3.2.4. Payload weight and size for these missions are as specified by the NASA (Reference A-1), while orbit definitions and delta-V requirements were established on the basis of similar missions in the NASA Payload List.

AUTOMATED LUNAR PROGRAM

The automated lunar program option is incorprated in the parametric space mission program at the "D" and "E" levels.

The basic concept of the automated lunar program is described in Reference A-2. This reference is a report of the 1970 Summer Study conducted by the Space Science Board of the National Research Council. The report offers three optional automated lunar programs. Only option 1 includes traverse or sample return capability. An excerpt from the reference which introduces the option 1 program follows:

"Automated Lunar Program (ALP) with orbiters, landers, rover traversing, and sample return capability. This is seen as the next truly significant step in lunar exploration beyond Apollo; it would provide data about the moon at local, regional, and global levels. Five orbiters would each carry a 100-kg science payload, with relay tracking satellites for gravity surveys, electromagnetic sounding, infrared spectroscopy, and side-looking radar. Each of five landers would put down a 1500-kg science payload that would include an Apollo Lunar Surface Equipment Package (ALSEP)-type stationary science station, a 300-kg rover that could carry a science payload and collect samples over a traverse distance of 100 km, and a sample return system that could send 15 kg of lunar material back to earth. This option has great scientific capability. The information it would produce in many fields, added to the information obtained by the Apollo program, should greatly refine our concepts of the moon, the early earth, and the solar system. It would also serve as a conceptual, developmental, and testing exercise for eventual automated missions to Mars and perhaps to other planets and satellites. The estimated cost over a 10-year period would amount to about $1.4 billion, a small fraction of Apollo costs."

The reference also includes the following summary data.

Table A-1 . Summary of Automated Lunar Program
Option 1 - Launch Dates 1978 - 1982

Description	Candidate Experiment	Number of Missions
1. Study surface and interior by an advanced orbiter	Orbiter: Imagery, gravity magnetics, composition by remote sensing, plus electromagnetic sounding, infrared, altimetry	5 orbiters
2. Land scientific stations comparable to ALSEP	Landed science: Similar to Apollo ALSEP for study of interior, imagery, bulk composition, and geochemistry	5 landers
3. Traverse science (rover) with 100-Km range	Traverse science: Deployment arrays, regional geological, geochemical, and geophysical studies	
4. Sample return to earth	Sample return: Laboratory analysis of samples collected during traversing for age, composition, evolution, etc.	

a. Orbiter Weights

Estimates of the orbiter weights are derived from comparison with other similar spacecraft. For the purposes of the ISPLS study, the advanced lunar orbiter is related to the Lunar Orbiter spacecraft which was developed and flown in the mid-1960's prior to the Apollo lunar missions.

The Lunar Orbiter, developed for NASA by the Boeing Company, weighed about 850 lb and carried about 150 lb of scientific payload. The payload consisted largely of a photographic package comprising camera, film, processor, and readout equipment. Resolution was about one meter. The spacecraft contained a retro system which inserted the spacecraft into the desired orbit using a two-burn program.

The advanced lunar orbiter for the contemplated automated lunar program is estimated to be heavier than the Boeing Lunar Orbiter by the ratio of the spacecraft's science payloads. Thus, the advanced orbiter would weigh :

$$850 \times (220/150) = 1250 \text{ lb}$$

The relay tracking satellites which accompany each of the orbiters are estimated to be smaller and lighter spacecraft. For the purposes of the ISPLS study the lunar relay tracking satellites are related to Syncom III, an early earth synchronous communications satellite which established the feasibility of communication from ground to aircraft via satellite using VHF and telemetry band equipment. Syncom III weighed 145 lb. Considering power and antenna requirements for the longer lunar communications range and the requirements to retro into lunar orbit, the relay tracking satellite weight at trans-lunar injection is estimated to be approximately 350 lb.

Thus, the injected payload for each advanced lunar orbiter and its relay tracking satellite is 1250 + 350 = 1,600 lb. The orbiter and its relay tracking satellite will be launched simultaneously. Optionally the relay tracking satellite may be inserted into lunar orbit by the orbiter and then released to make its own orbit adjustments. Either way, the ISPLS study may utilize the 1600 lb trans-lunar injection payload weight. The injection may be performed with a reusable tug or with an expendable stage.

b. Lander Weights

Estimates of the lander weights are derived from the Surveyor . . . as tabulated below.

Table A-2. Surveyor Weight Summary

	Weight lb
Scientific Payload	359
Telecommunications	48
Electrical Power (RTG)	76
Propulsion	1847
Spacecraft Vehicle	128
Guidance and Control	57
Spacecraft/Centaur Interconnect	23
Total on Centaur	2538
Main Retro Burnout	970
Touchdown	785

Note that propulsion accounts for the major portion of the Surveyor weight, 1847 out of 2538 lb or 73 percent. The retro motor is a spherical solid built by Thiokol. Performance is . . .

I_{sp}	289.5 sec
Thrust	8,000 - 10,000 lb
Delta-V	8,300 ft/sec

The ratio of Surveyor scientific payload to total injected weight is:

359:2538 or 14.2 percent

The lander for the contemplated automated lunar program will be much larger than the Surveyor since it will carry almost ten times the payload. Considering its larger size and the potential for employing a higher performance retro system, the scientific payload for the new lander should represent about 20 percent of the lander weight.

The lunar science payload for the lander, per the Space Science Board suggestion, is 1500 kg or about 3300 lb.

The lander gross weight including interconnect structure, therefore, is estimated to be:

$$3{,}300/0.20 = 16{,}500 \text{ lb}$$

As with the orbiter, trans-lunar injection would be performed with a reusable tug or an expendable stage.

Five automated lunar program orbiters (with relay tracking satellites) constitute the L-1 missions in the parametric Space Mission Program;

five landers comprise the L-2 missions. The mission schedule was deferred by two years to the 1980 - 1984 period to reflect budget constraints. This also provided for inclusion of the fully automated lunar program within the time period of the ISPLS study.

MANNED LUNAR PROGRAM

As in the case of the automated lunar program option, the manned lunar program option is incorporated in the parametric space mission program at the "D" and "E" levels. However, while the automated lunar missions are planned for the 1980 - 1984 time period, the manned lunar missions are considered to follow the automated missions, and they have been scheduled for the 1986 - 1990 time period.

Manned lunar mission requirements have been established on the basis of providing support for the Orbiting Lunar Station and the Lunar Surface Base. This support established the cislunar shuttle payload requirements, which were included in the Guidelines and Constraints for this study (Reference A-3). In accordance with these Guidelines and Constraints, a lunar mission return payload weight of 15,000 pounds was selected for this study. This return payload weight permits an outbound payload of 175,000 pounds if the RNS is employed as the cislunar shuttle in the Mode 1, minimum energy operating condition. The same outbound/inbound payload ratio was selected for the CIS in order to provide a basis for comparing the two lunar shuttle candidates.

The lunar mission flight frequency of two per year was agreed upon during an NR-NASA working group meeting held during the first month of the Study. The minutes of this meeting are documented in Reference A-4.

ILLUSTRATIVE AUGMENTED PLANETARY MISSIONS

The augmented planetary missions, which could be performed with a CIS or RNS by the mid-1980's are introduced only in Program Level E. The mission program described herein is illustrative of the potential of a CIS or RNS to support continuing automated exploration of the planets, but it does not reflect NASA documentation regarding mission program planning for the 1980's decade.

Manned lunar missions, which are introduced in Program Level D of the Parametric Space Program, also employ a CIS or RNS. These manned lunar missions involve two CIS/RNS flights per year, as indicated in the previous section. The augmented planetary missions are additive to the manned lunar traffic as regards employment of the CIS or RNS. Because the augmented planetary missions are ambitious and expensive compared with the current planetary program, projected flights were limited to a total of five over the seven-year period 1984 - 1990. Adding these five missions to the two-per-year lunar flights yields the schedule shown in Figure A-1.

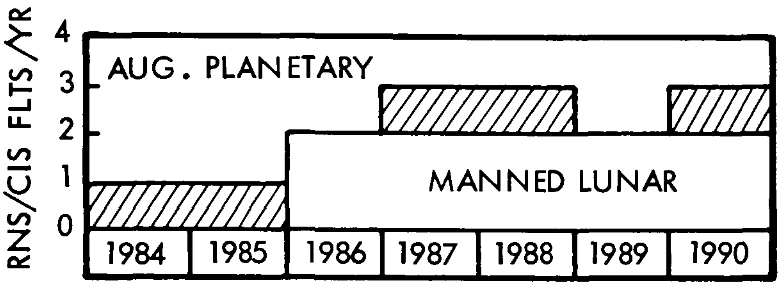


Figure A-1 CIS/RNS Flight Schedule for Program Level "E"

Table A-3 Mission-Payload Summary for Illustrative Augmented Planetary Missions

MISSION			INJECTION ΔV* FROM 180 nmi (FT/SEC)	PAYLOAD INJECTED WEIGHT (LB)	CIS/RNS OPERATING MODE
NO	TITLE	YR			
P-3	MSSR	'84	15,115	134,000	SELF-RETURN
P-2	VSSR	'85	13,115	185,000	SELF-RETURN
P-4	JUPITER-IO	'87	22,415	70,000	EXPENDED
P-3	MSSR	'88	15,115	134,000	SELF-RETURN
P-4	JUP. TOUR-GANY	'90	22,415	70,000	EXPENDED

*THEORETICAL ONE-WAY ΔV

Table A-4 Propellants Required for Illustrative Augmented Planetary Missions

NO.	MISSION	YR	PROPELLANTS CONSUMED -LBS	
			CIS	RNS
P-3	MSSR	'84	498,000	195,000
P-2	VSSR	'85	498,000	195,000
P-4	JUPITER-IO	'87	755,000	244,000
P-3	MSSR	'88	498,000	195,000
P-4	JUP. TOUR-GANY	'90	755,000	244,000
	TOTAL		3,004,000	1,073,000

The illustrative augmented planetary missions selected for inclusion in this study are:

1984 Mars Orbiter, Surface Sample and Return (MSSR)
1985 Venus Orbiter, Surface Sample and Return (VSSR)
1987 Jupiter Orbiter, Probes and Io Lander/Rover (Jupiter-Io)
1988 Second MSSR (or alternately a second VSSR)
1990 Tour of the Galilean Satellites, Ganymede Lander/Rover (Jupiter Tour - Gany.)

All of these missions are complex, high-energy missions. For the purpose of defining mission payloads and propellants required for use in the ISPLS Parametric Space Program, all are configured for employment of a CIS or alternately an RNS. For trans-Mars or trans-Venus payload injection, the CIS/RNS are employed in the reusable mode, requiring return to earth orbit after payload separation. Optional modes for trans-Jupiter payload injection include:

Expending of the CIS/RNS in payload injection

Expending of a tug as a second injection stage on top of a CIS or RNS which is employed as a self-returned recoverable stage

Both are viable options for mission planning. Reference to Figure A-1 shows the 1987 Jupiter mission to be nominally the sixth flight of the first operational CIS/RNS. Since this may be a reasonable life (six flights/three years) for the first operational article, the article is considered here to be expended. The second Jupiter mission, 1990, is eight flights and three years later. Similarly, this represents a reasonable life for the second article, which, therefore, is also considered to be expended.

Summary data for these augmented planetary missions are presented in Table A-3. The injection delta-V's in this table were calculated by NR on the basis of appropriate flight trajectories. (In later computation of propellants required for the P-2 and P-3 missions, which involve stage self-return, an additional ten percent delta-V was added to account for mission losses. For the P-4 missions, in which the CIS/RNS are expended, a five percent delta-V increment was added.) Propellants required for the missions in Table A-3 are identified in Table A-4.

Selection of illustrative augmented planetary missions for the 1984 - 1990 time period has been guided by the rationale and long-term strategy for planetary exploration offered by the Space Science Board in Reference A-2. Brief discussions of each of the five missions in the program are presented in the following paragraphs.

Mars Surface Sample Return (P-3)

The Mars Surface Sample Return (MSSR) mission concept identified as Concept I-I(2) in Reference A-5 serves to define the trans-Mars injected payload for the P-3 missions in the Parametric Space Program.

Major mission roles are:

- Return of samples and films from Martian surface
- High resolution mapping from high data rate orbiter
- Mobile surface exploration

The recommended baseline MSSR system included:

- Conjunction mission
- Orbiter/bus-probes
- Ballistic Mars entry out of circular orbit
- Dual lander/return probes with independent rovers
- Mars orbit rendezvous/earth return
- Earth capture/recovery

Table A-5 presents a condensed version of the weight summary from Reference A-5.

Table A-5. Weight Summary for MSSR Concept I-I(2)

Payload Element	Weight-lbs
Total Probes (2) with Cannisters	32,890
Probe Mounting Structure	3,290
Probe Adapter	1,630
Orbiter/Bus	8,460
Mars Departure Stage	10,920
Mars Braking Stage	73,540
Total Planetary Vehicles	130,730
ELV Adapter	3,270
Earth Departure Payload Weight	134,000

Two MSSR missions are included in Program Level E of the Parametric Space Program, one in 1984 and the second in 1988. Optionally, the 1988 mission could be programmed for Venus Surface Sample Return. The second MSSR mission is shown here since it is better defined and reflects potential priority.

Venus Surface Sample Return (P-2)

The Venus Surface Sample Return mission represents a major growth step in a program of Venus exploration consisting of the following missions:

. Mariner 2	1962
. Mariner 5	1967
. Mariner Venus/Mercury	1973
. Venus Explorers (Orbiters, Probes, Hard Landers, Floating Stations)	1975-1980
. Venus Radar Mapping	1982

Development of the VSSR spacecraft would benefit from more environmental data, particularly for the Venusian surface, than would be derived from the above sequence of missions. Consequently, a vigorous planetary program which includes a VSSR mission in 1985 should also include the Venus Explorer Lander mission, No. 54, but accelerated in schedule to either the 1980 or 1982 opportunities.

Estimates of the VSSR earth departure payload are projected from the MSSR earth departure payload. The VSSR system, like the MSSR system, is configured with orbiter/bus-probes and dual lander/return probes with independent rovers. The VSSR system also employs ballistic entry out of a circular orbit, rendezvous of the Venus sample ascent vehicle with the Venus orbiter for earth return, and earth capture/recovery. In-space elements of the system-trans-Venus injection stage, Venus orbit insertion system, Venus orbiter, earth-return propulsion and earth entry/recovery elements -- are modifications of the MSSR counterparts. Extended propellant tankage is required for Venus orbit insertion and trans-earth injection.

The high-temperature - high-pressure environment of Venus, however, makes the Venus probe a more difficult design problem. The dense, high-temperature atmosphere and the higher Venus gravity increase the "payload" weight and energy requirements for ascent from the surface. The combined effect of these more difficult requirements is estimated to increase the earth departure payload weight to about 185,000 pounds.

Jupiter Orbiter, Probes - IO Lander/Rover (P-4)

Guidance for identifying advanced Jupiter exploration missions for incorporation into the illustrative augmented planetary program was derived from References A-2, A-6, and A-7.

The illustrative augmented planetary program introduces the first heavy Jupiter mission employing a CIS or RNS in 1987 so as to build upon the evolutionary Jupiter exploration program commencing with the Jupiter Pioneer mission in 1972 through the Jupiter TOPS Orbiter probe by the mid-1980's. Additionally, the orbiters to be employed in the augmented missions should be growth versions of the TOPS orbiter.

Estimates of the composite spacecraft for this compound mission are derived from Reference A-8. The spacecraft includes two separable orbiters with advanced entry probes, the latter containing deorbit propulsion; an orbit insertion stage for each orbiter/probe; and a separable Io Lander spacecraft. Weights are summarized in Table A-6.

Orbit insertion of each orbiter/probe is performed with an orbit propulsion system utilizing space-storable FLOX/methane which yields a specific impulse of 400 seconds. The propulsion system weight given in Table A-6 provides a delta-V capability slightly in excess of 8400 ft/sec for insertion into an orbit having an eccentricity of 0.9 and R_p/R of 1.5.

Table A-6. Summary Weight Estimate for Jupiter Orbiter, Probes and Io Lander/Rover Spacecraft

Payload Elements		Weight-lbs
Adv. Orbiters/Probes	8,300 each x 2	16,600
Orbiter Spacecraft	2,000 each	
Probe	1,000 each	
Contingency	300 each	
Propulsion	5,000 each	
Io Lander		44,600
Basic Spacecraft	1,525	
Contingency	210	
Propulsion (Retro & Land)	1,660	
Propulsion (Orb. Insert.)	10,405	
Propulsion (Orbit. Insert.)	30,800	
Adapter and Multiple Spacecraft Support		4,000
Growth Allowance		4,800
Earth Departure Payload Weight		70,000

The Io lander concept employs a two-stage orbit insertion propulsion system utilizing FLOX-methane propellants. The lander propulsion system employs a large solid motor and throttleable liquid engines. The Viking lander terminal descent propulsion system (hydrazine monopropellant) appears applicable to the Io lander. Of the 1525 pound landed weight, about 350 pounds is estimated to be available for scientific equipment including a small rover.

Tour of Galilean Satellites, Ganymede Lander/Rover

A technique for exploiting orbiting Jupiter spacecraft to repeatedly encounter the Galilean satellites is presented in Reference A-9. The reference notes that the four Galilean satellites of Jupiter -- Io, Europa, Ganymede, and Callisto -- "are of considerable scientific interest in their own right. --- Of the four, Ganymede is larger than the planet Mercury, and Io and Callisto are both larger than the earth's moon. These bodies might more correctly be called semiplanets whose properties bear on the general problem of the origin of the solar system."

"A key feature of the technique is the characteristic of repetitive satellite encounters which results from matching orbits with the commensurable motion of Io, Europa, and Ganymede . . . The orbital periods of Io, Europa. and Ganymede are very close to the ratio of 1:2:4, respectively. . . . This relation repeats itself every seven days (Ganymede's period) . . . . The motion of Callisto, the fourth Galilean satellite is not commensurate with the system."

"Since approach conditions are quite stable for all Jupiter mission opportunities, it can be concluded that generally favorable satellite flyby conditions will always exist."

The "semiplanet" Ganymede is about 3260 miles in diameter, has a semi-major axis of 15 Jupiter radii and an orbital period of 15 days. The delta-V requirement for insertion into the Ganymede orbit at 15 Jupiter radii is almost 4000 ft/sec less than that required for insertion into the Io orbit at 5.9 Jupiter radii. However, Ganymede is larger than Io (3260 versus 2240 miles) and has more than twice the mass. Being larger than Mercury (3029 miles in diameter), Ganymede may have an atmosphere. Lack of data regarding Ganymede's atmosphere would make the lander entry phase difficult to analyze at this time.

Since implementation concepts for the Ganymede lander/rover and the TOPS derivative orbiters that may be employed in the repetitive encounters with the Galilean satellites are not available, the earth departure payload weight of 70,000 pounds as derived for the Jupiter Orbiter, Probes, and Io Lander/Rover mission is assumed to be reasonable for this mission was well.

REFERENCES

A-1 Letter No. PD-SA-0 (71-114) dated October 14, 1971, from NASA/MSFC to North American Rockwell/Space Division, Subject: In-Space Propellant Logistics and Safety Study (NAS8-27692)

A-2 "Priorities for Space Research 1971-1980," National Academy of Sciences, 1971

A-3 "Statement of Work for an In-Space Propellant Logistics and Safety Study," Appendix A, National Aeronautics and Space Administration, George C. Marshall Space Flight Center, March 11, 1971

A-4 NR Internal Letter SLV-595-201-71/315 dated July 23, 1971, Subject : Minutes of NR-NASA Working Group Meeting on ISPLS Contract Tasks, Seal Beach, 21 July 1971

A-5 "Final Briefing, Mars Surface Sample Return (MSSR) System," Northrop-Huntsville, January 1970

A-6 "1972 NASA Authorization, Hearings Before the Sub-committee on Space Science and Applications," H.R. 3981 (no. 2) Part 3

A-7 "The Outer Solar System, A Program for Exploration," Space Science Board, National Academy of Sciences, 1969

A-8 "Outer Planet Exploration Missions," Final Report North American Rockwell, Space Division, Report Nos. SD70-32-1 and -4, January 1970

A-9 "Touring the Galilean Satellites," by John C. Niehaff, Paper presented at the Astrodynamics Conference, Princeton, New Jersey, 1970

APPENDIX B

PAYLOAD PROPULSIVE STAGES (PPS)

Payload propulsive stages for use in performing payload placements and retrievals, payload injection missions and interorbital shuttle missions beyond the capability of the space shuttle have been identified in Figure B-1. The figure also includes PPS size and weight summary data.

This section presents further information about the payload propulsive stages. Configuration, weights, performance and some operations data are included. The payload propulsive stages are:

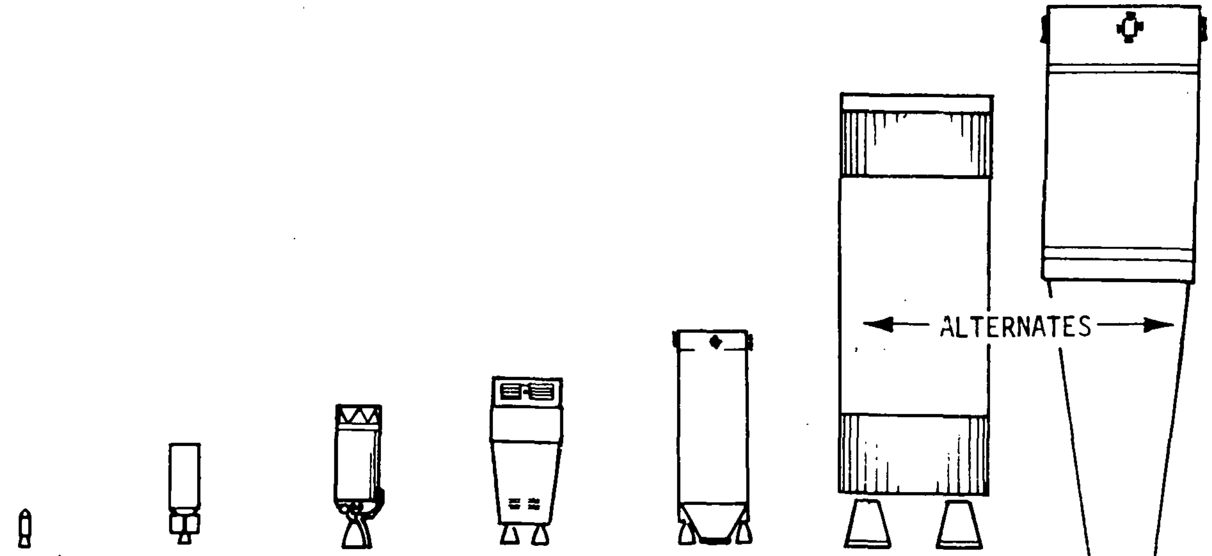
Ground-based, expendable:	FW-4S Agena Centaur
Ground-based, reusable:	Tug (OOS)
Space-based, reusable:	Space Tug RNS CIS

FW-4S KICKSTAGE

The United Technology FW-4S "Kick Stage" has been identified in the space traffic models as an expendable propulsive stage to be utilized in conjunction with the Shuttle to deliver payloads for mission categories of: Physics and Astronomy, Earth Observation, Communication/Navigation and non-NASA missions. This motor features a unique "consumable" rocket type igniter which burns during engine combustion and contributes to the total impulse. The nozzle is constructed of low-density silica material and has an expansion ratio of 52.8:1. The case is filament wound of an advanced high-strength glass and varies in length dependent upon the propellant loading. The FW-4S stage utilized in this study is 6.8 feet in length, 2.1 feet in diameter and weighs 860 pounds. During a 31.5-second burn the FW-4S develops an average of 5857 pounds of thrust in a vacuum when spinning at 200 RPM. The I_{sp} is 284 seconds in vacuum. Performance capability of the FW-4S was obtained from NASA's launch vehicle estimating factors of Reference B-1.

AGENA

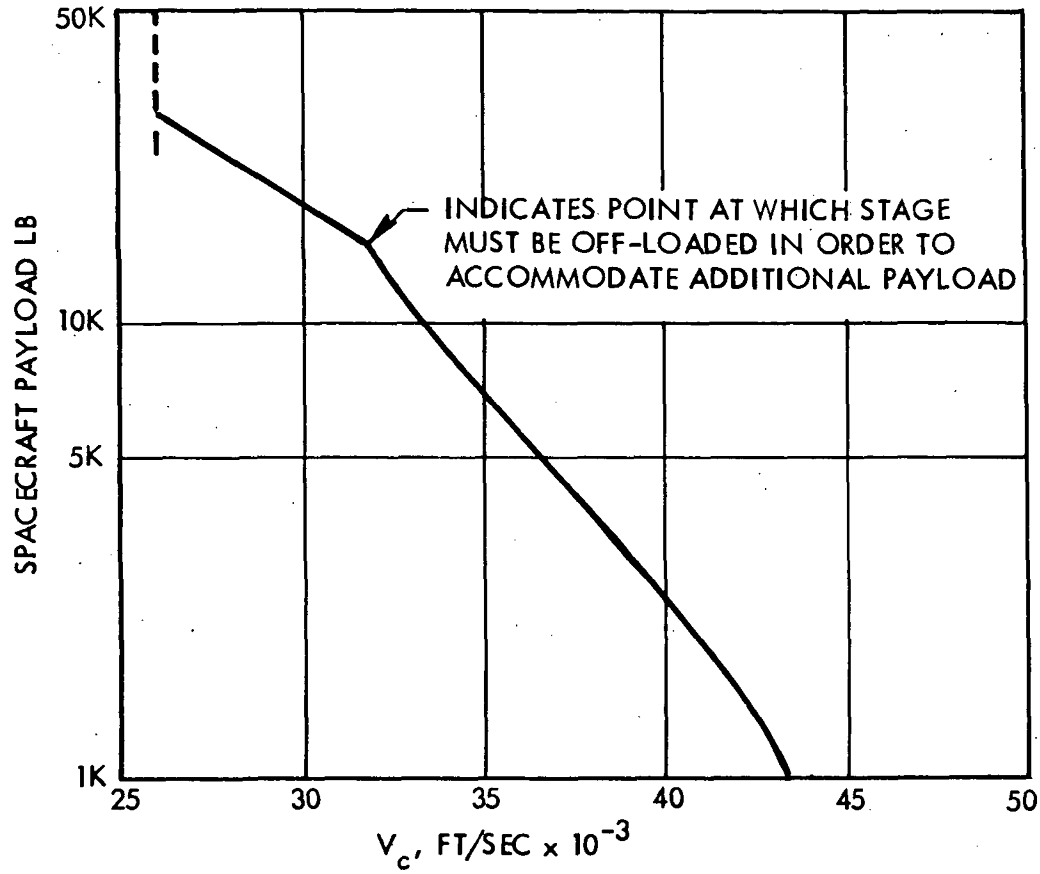
As in the case of the FW-4S stage, the Agena will be utilized as an expendable third stage of the space transportation system to place payloads of the space traffic models in their desired orbits. Physical characteristics of the Agena are defined by an overall length of 20 feet, a diameter of five feet and a dry weight of 1,400 pounds (see Figure B-2). It has a capacity of 13,600 pounds of propellant consisting of inhibited red fuming nitric acid (IRFNA) oxidizer and unsymmetrical dimethyl hydrazine (UDMH) fuel.



	GROUND-BASED				SPACE-BASED		
CHARACTERISTICS	FW4S	AGENA	CENTAUR	TUG (OOS)	SPACE TUG	CIS	RNS
LENGTH - FT	6.8	20	31.5	36	47	100	194
DIAMETER - FT	2.1	5	10	15	15	33	33
WEIGHTS - LB							
GROSS	860	15000	35,300	67,500	83,400	1,095,000	377,000
PROPELLANT	–	13600	30,200	60,200	73,200	990,000*	300,000*
EXPENDABLE	X	X	X				
REUSABLE				X	X	X	X
IN SPACE PROP. RECEIVER					X	X	X

*LUNAR MISSION MODE 1 REQUIREMENTS

Figure B-1 Payload Propulsive Stages



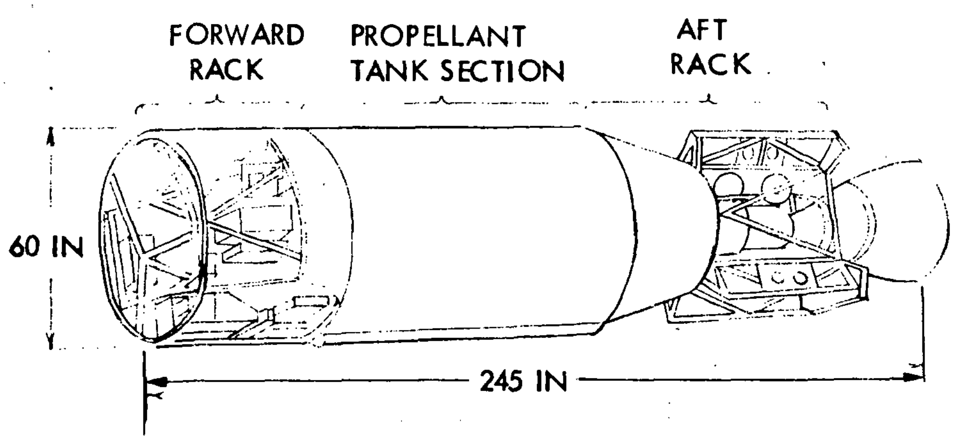


Figure B-2 Agena Vehicle

The Agena functions are performed by five systems identified as spaceframe, propulsion, guidance and flight control, electrical power, and tracking and communications. The spaceframe is comprised of: the forward section where the bulk of Agena's guidance, electrical power, propellant and pressurization and communication equipment are located; the propellant tank section which is the reservoir for the fuel and oxidizer and serves as the supporting structure between the forward and aft sections; and finally, the aft structural section which supports the engine and attach point for secondary payloads.

In addition to the engine, the propulsion system includes propellant pressurization, containment and scavenging components. The pressurization system is a "blowdown type" in which the flow of helium gas from the high-pressure storage tank to the propellant tanks is controlled by fixed orifices. Surface tension-type propellant containment and scavenging devices maintain propellant orientation for engine starts in the zero-g environment.

The rocket engine is a Bell Aerosystems Company model 8096 that is turbopump-fed with liquid propellants and develops 16,000 pounds of thrust. The engine has a single combustion chamber which is regeneratively cooled by the oxidizer that passes through the thrust chamber walls and throat prior to entering the injector, and the expansion nozzle is cooled by radiation. The engine is mounted in a gimbal ring that allows the engine thrust vector to be varied for pitch and yaw control during engine operation. Hydraulic actuators supply this motive force for thrust chamber movement in response to signals sent by the guidance system. Roll control is provided by cold gas thrusters throughout the flight. During coast periods between engine firings attitude control thrusters provide control in all three attitude axes.

Electrical energy is supplied by internally mounted silver-zinc primary batteries. The batteries are connected in parallel to a main power bus; however, one is diode-isolated and serves as a pyrotechnic power supply. The Agena may be configured with rigid or extendable solar array panels for long-term missions.

The Agena is guided by a strapdown inertial reference assembly with an 8,192-word memory digital computer. Mission-peculiar programming is accomplished through software adjustments. The digital computer also provides accurate timing, command storage and real-time command processing. It controls all electrical switching and sequence of events, processes the attitude sensor data, and issues thruster and actuator commands to Agena flight control electronics.

Telemetry and tracking functions are provided through: (1) a 200-channel, high sampling rate, wide-band PCM telemeter, (2) a two-watt S-band transmitter, and (3) a 300-watt (peak pulse) C-band transponder. The on-board digital computer is shared with guidance, control and command functions.

Thermal control is maintained by passive techniques, using selected surface coatings, isolation, and insulation. Thermally actuated electrical heaters are also employed for critical components.

The modular forward and aft equipment section designs provide a variety of locations for environmentally sensitive payloads, payloads with critical view angles, and multiple payloads. The Agena spacecraft can provide active support to payloads for periods up to six months (power on, active attitude control). Several Agena spacecraft have operated in the semiactive mode for periods over two years.

A plot of Agena upper stage performance capability is shown in Figure B-2. The sharp bend in the performance curve indicates the point at which the stage must be off-loaded to accommodate additional payload. Performance data were obtained from NASA's launch vehicle estimating factors of Reference B-1.

CENTAUR

System description and performance characteristics of the Centaur stage are based on a preliminary investigation of Centaur/Shuttle Integration (See Reference B-2). The missions for Centaur application are unmanned wherein the Centaur is the expendable third stage of the space transportation system.

Figure B-3 illustrates the basic Centaur D-IT configuration. The tank structure consists of a thin-walled, 301 stainless steel monocoque cylindrical section, capped at both ends by stainless steel bulkheads. A double-walled insulated, ellipsoidal inner bulkhead provides separation between the liquid oxygen (LO_2) tank and the liquid hydrogen (LH_2) tank. The payload support structure is designed to carry payloads on a truss structure with a 10-foot interface diameter.

Primary vehicle thrust is provided by two Pratt and Whitney RL10A-3-3 engines which are capable of performing multiple engine starts in space, and have the following performance characteristics:

Thrust (Nominal)	15,000 lb
Chamber Pressure	400 psia
Mixture Ratio (Nominal)	5:1
Specific Impulse, I_{sp} (nom.)	444 sec
Rated Operating Duration (per firing)	450 sec

The airborne tank pressurization subsystem consists of a helium bottle, tubing and various components required to deliver pressurized helium from the storage bottle to the tanks. After tanking, boiloff provides pressurization which is regulated by vent (boil-off) valves on each tank. Propellant tank pressurization is increased prior to each start to prevent boost-pump cavitation by increasing the net positive suction head.

The propellant feed system consists of fuel and oxidizer sump mounted boost pumps, propellant feed ducts, and recirculation lines to maintain liquid at the engine inlet shutoff valves.

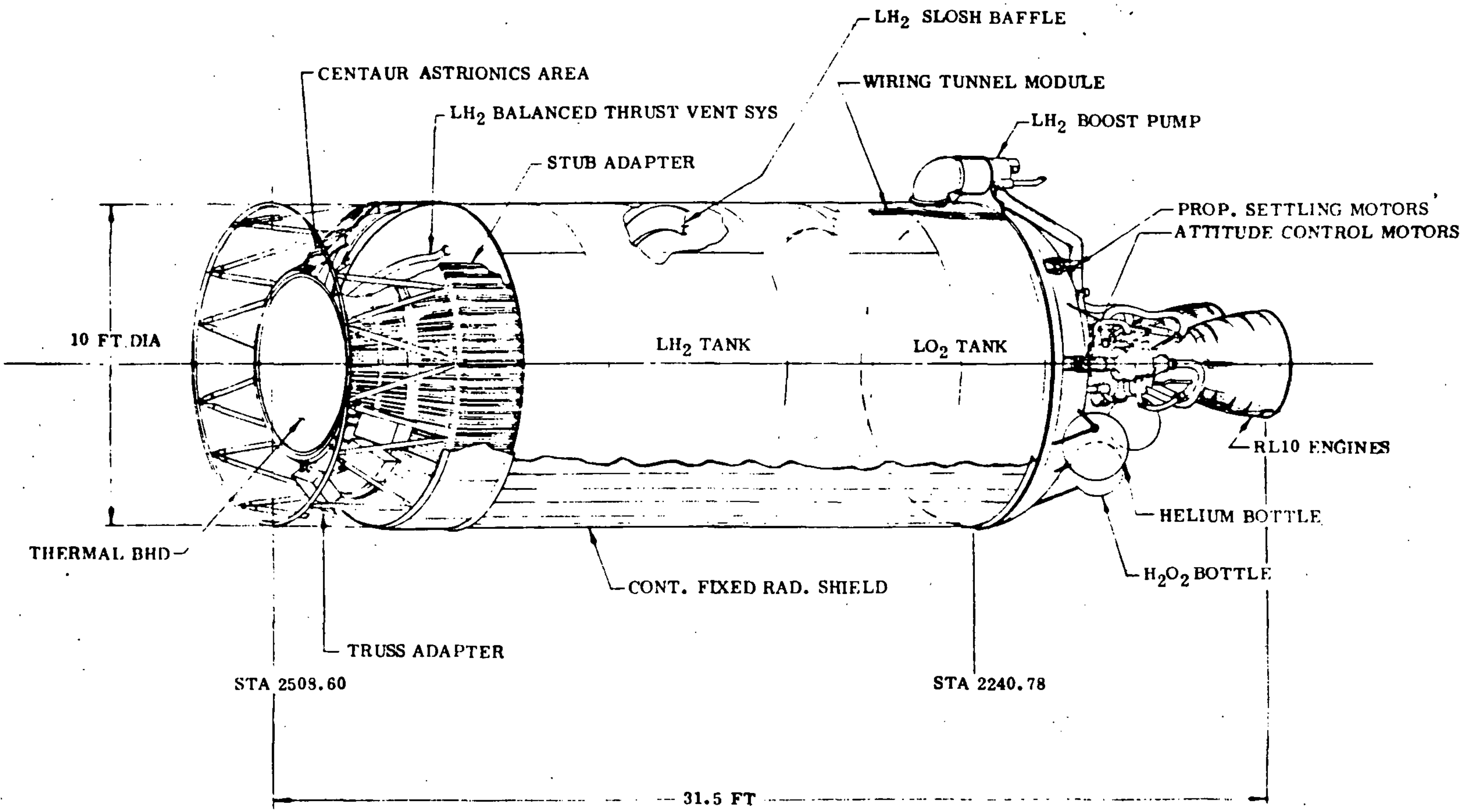


Figure B-3 D-IT Centaur Configuration

Propellant flow is initiated by a centrifugal-flow boost pump submerged in each propellant tank. A propellant utilization system adjusts the propellant mixture ratio of the main engines to ensure that propellant residuals at the termination of powered flight are at a minimum.

The cylindrical portion of the liquid hydrogen tank is insulated by a radiation shield consisting of three layers of aluminized Mylar. The shield is effective against solar heating and earth radiation and improves the capability of the Centaur D-IT to perform long coast missions by significantly reducing hydrogen boiloff.

The Centaur astrionics system for performing the guidance, navigation and control functions consists of the following units: (1) a digital computer with a 16,384 word by 24 bit ferrite core memory with a stored program; (2) an inertial measurement group (inertial reference platform and system electronics unit) in conjunction with the digital computer unit makes up the Centaur vehicle inertial guidance system; (3) a sequence control unit provides pre-launch and in-flight control of the vehicle systems and contains a relay switch section, a decoder section and a power switch section; (4) the servo inverter unit provides control of the engine actuators by signals from the digital computer unit; and (5) the propellant utilization system provides in-flight control of the propellant masses to minimize end residuals.

The electrical power system supplies and distributes 28-volt DC power and distributes 115-volt and 26-volt, single phase, 400-Hz AC power to the various Centaur systems.

REUSABLE GROUND-BASED TUG (OOS)

Characteristics of the ground-based tug selected for use in this study were obtained from the Orbit-to-Orbit Shuttle (OOS) Study, References B-3 and B-4. At the conclusion of the conceptual design phase of this study, three concepts were selected as being the most viable propulsion concepts. These concepts were:

a. Single stage, single ellipsoidal tanks
b. 1-1/2 stage, nested tanks
c. Dual stage, ellipsoidal LH_2 tank and toroidal LO_2 tank.

It was not the purpose of the tug study to select a particular concept; however, the single stage concept appears to be the most attractive for the following reasons. The single stage configuration provides the virtues of overall design simplicity, minimum complexity (and variation) in structural support interface with the shuttle orbiter cargo bay, minimum complexity of fluid interconnects, minimum operational complexity due to configuration invariability, and high efficiency due to favorable size factors.

The general arrangement of the single-stage tug (OOS) vehicle, whose overall dimensions are 15 feet in diameter and 36 feet long, is shown in Figure B-4. The propellant supply system has two single tanks. The liquid hydrogen tank is 173 inches in diameter with a tank volume of 2168 cubic feet. End bulkheads are elliptical with an end area ratio of 1.4:1. The liquid oxygen tank is a 151.6-inch diameter ellipsoid (1.4:1) with a capacity of 776 cubic feet. Propellant tanks are supported on aluminum integral tank Y rings. The hydrogen tank has integral Y rings at each end of the cylindrical portion of the tank. This cylindrical section of the tank becomes the basic vehicle shell structure and is identified as an integral tank. The liquid oxygen tank has only one integral Y ring to which the support skirt is attached. This tank is not a part of the vehicle structure.

The thermal control system for OOS is a multilayer insulation system with a controlled dry gas purge system for transition from earth into space and back. Each main area of the vehicle has a controllable purge valve for venting the annulus cavities.

The propulsion system consists of two 10,000-lb thrust fixed Bell engines with a specific impulse (I_{sp}) of 470 seconds and an expansion ratio of 400, chamber pressure of 1400 psi, and mixture ratio of 6:1. Four ACS clusters are located 90 degrees apart on the aft portion of the vehicle. Each cluster has five engines, one facing forward, one to each side, and two facing aft. Each engine has 100-lb thrust, I_{sp} of 386 sec, expansion ratio of 40, chamber pressure of 250 psi and a mixture ratio of 4.2:1 (GO_2/GH_2).

The subsystems are divided into two groups. One is located on the forward bulkhead of the OOS and consists of guidance and navigation equipment, data management equipment, communication equipment and the environmental control system for avionics. The rest of the avionic equipment is located on the forward conical closeout structure. The remainder of the subsystem equipment such as ACS equipment, the EPS and the ECS equipment, is located on the aft engine thrust structure.

The tug (OOS) missions are primarily those of payload deliveries to or payload retrievers from orbits beyond the capabilities of the space shuttle. For payload delivery missions, the OOS-payload attachment is a simple ring clamp which can be released with pyrotechnics. On payload retrieval missions, a mechanical docking probe is installed on the forward centerline of the OOS and is used for capturing and locking the payload to the OOS in space and returning it to the shuttle orbiter.

The propellant requirement for the tug design mission is 60,200 pounds, resulting in a gross vehicle weight of 67,500 pounds. The tug 7,300-pound inert weight includes the stage dry weight and residuals/reserves. The main propellant weight of 60,200 pounds is comprised of impulsive propellant, auxiliary propellant, operational engine losses, and vented propellant.

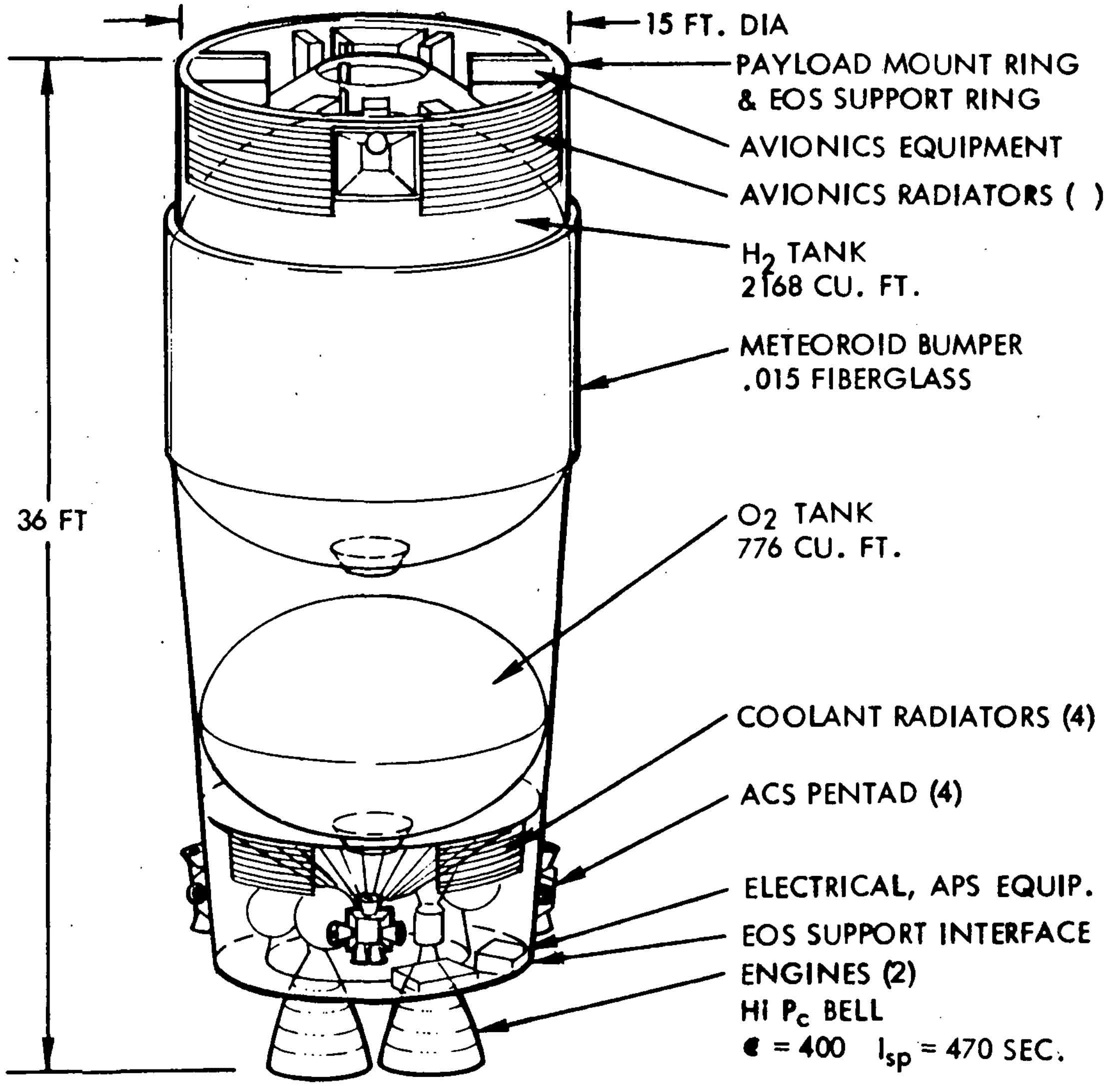


Figure B-4 Single Stage Concept

REUSABLE SPACE-BASED TUG

Characteristics of the space-based tug selected for use in the In-Space Propellant Logistics and Safety study were obtained from Reference B-5. The design concept selected is one of many analyzed in the pre-Phase A study conducted by the NR Space Division under contract to the NASA/MSC.

From the numerous space tug configurations studied, three emerged as representing distinctly different feasible approaches.

a. A single-stage, internal tankage concept
b. A two-stage, internal tankage concept
c. A one-and-one-half stage concept comprised of a limited-capacity, recoverable, reusable propulsion module and an expendable tank set.

The single-stage concept has been accepted as preferred, primarily on the basis of favorable complexity and economic ratings.

Figure B-5 presents the configuration of the single-stage concept and summarizes its operational characteristics. The design concept incorporates two modules: (1) a propulsion module, and (2) an intelligence module.

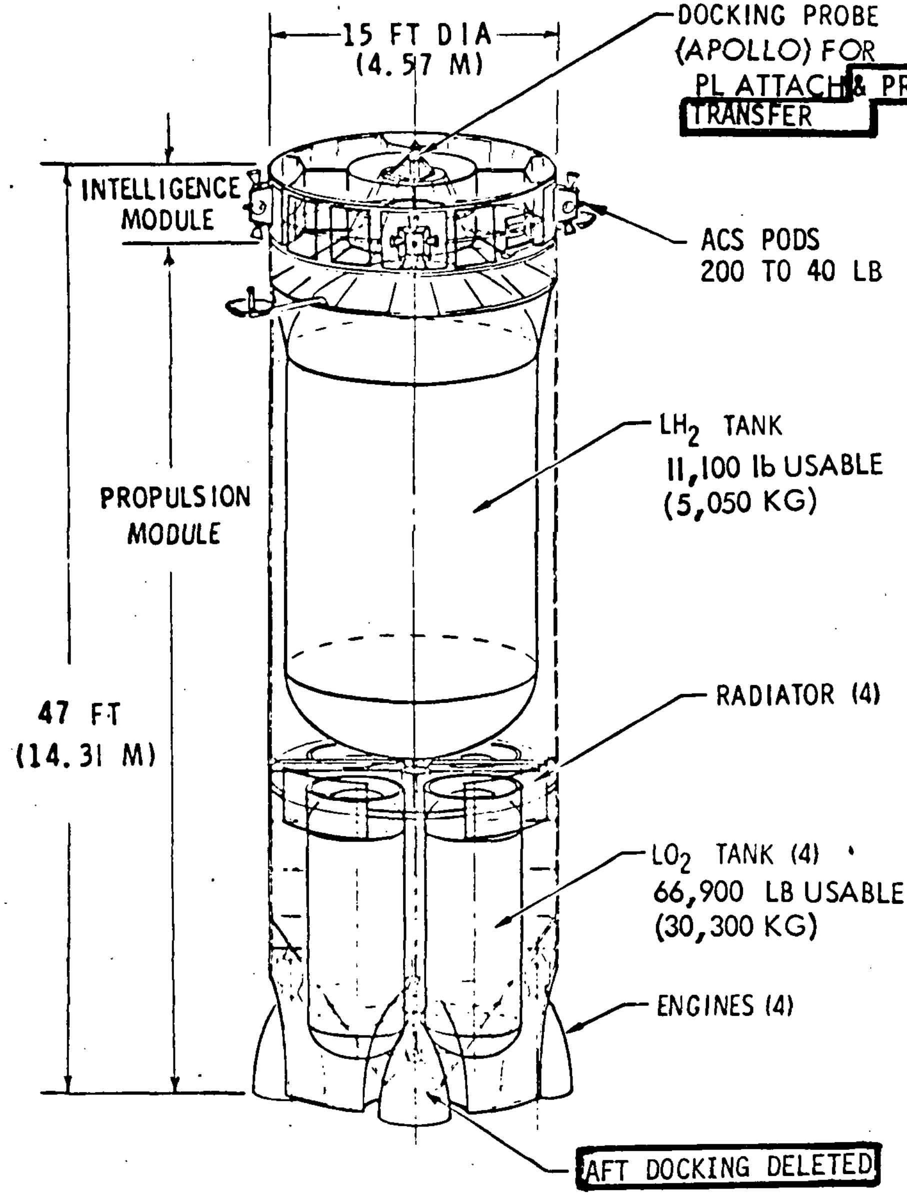
The propulsion module has four high chamber pressure engines located around a central Apollo-type docking ring. The propellant tankage consists of one hydrogen tank and four LO_2 tanks. These tanks supply the auxiliary systems as well as the main propulsion system.

The intelligence module is designed for autonomous space-based operations. It contains components necessary to conduct unmanned missions when combined with the propulsion module, or to conduct manned missions when combined with the propulsion module and crew module. It provides control of the main propulsion system thrust level and thrust vector orientation; rotational and translational control for precision maneuvering (e.g., docking); programming of all flight functions; guidance and navigation; power; and other functions.

The space tug is to be capable of economically performing all earth-orbital propulsive missions beyond the low earth orbit capability of the space shuttle. It is also to be capable of injecting payloads for near-planet missions and of returning to low-earth orbit for reuse.

The reusable space tug design conceptually is to be manrated. Also the design concept is compatible with projected requirements for a lunar landing tug, the lunar landing tug being derivable through kit-type additions to the basic design.

The incorporation of these broad capabilities, particularly the manrating and lunar landing tug compatibility, plus other features such as the separate intelligence module, increased the size and weight of this space-based tug concept. Weights are:



ISPLSS BASELINE TUG

- HAS BASIC MISSION CAPABILITIES OF PAYLOAD INTERFACE, PAYLOAD PLACEMENT AND SPACE BASED ORBITAL OPERATIONS (FURTHER DEFINITIONS AS GIVEN IN SD71-292, CONFIGURATION 1). ADDITIONAL CAPABILITIES OF PERTINANCE TO PROPELLANT LOGISTICS ARE GIVEN BELOW.
- IS ACTIVE VEHICLE IN RENDEZVOUS & DOCKING; DOCKING FIXTURE NEEDS ACCURATE INDEXING FOR TRANSLINE ALIGNMENT (NOT PROVIDED BY APOLLO FIXTURE).
- HAS PROPELLANT FILL LINE RECEPTACLES AT FWD END; MUST RELY ON PROPELLANT SUPPLIER FOR LINE INTERCONNECT MECHANISM.
- PRESUMABLY HAS GAS RETURN & VENT LINES, GAGING ETC. DESIGNED TO RECEIVE PROPELLANTS WITH SETTLING TOWARD AFT END.
- HAS NO PROVISIONS TO SUPPLY PROPELLANTS
- COULD PROVIDE THRUST FOR ROTATIONAL SETTLING OF PROPELLANT.
- COULD NOT THRUST FOR LINEAR PROPELLANT SETTLING (ACS THRUST TOO HIGH).
- COULD SUPPLY POWER FOR MONITORING, VAVLE ACTUATION & GENERAL HOUSEKEEPING REQUIREMENTS OF A LOGISTICS TANK, BUT NOT TO RUN THE COMPRESSORS DURING PROPELLANT TRANSFER.

NOTE: ITEMS ENCLOSED BY A HEAVY LINE ( ) INDICATE ASSUMED DEVIATIONS FROM TUG STUDY TO MAKE A MORE REALISTIC TUG CONFIGURATION FOR THE ISPLS BASELINE TUG

Figure B-5 Space - Based Reusable Tug Concept

Burnout weight		10,200 lb
Propellant module	6,805 lb	
ACPS and astrionics	3,395 lb	
Propellant capacity		73,200 lb
Gross Weight		83,400 lb

Figure B-5 also notes suggested modifications to the space-based design concept to permit propellant resupply through the forward end. The payload performance was taken from Volume 3, page B-7 of Reference B-5.

REUSABLE NUCLEAR SHUTTLE (RNS)

The RNS is a candidate interorbital shuttle for the transfer of heavy payloads between low earth orbit, and lunar or geosynchronous orbit and return. Additionally, both the RNS and CIS offer space transportation system capabilities for potential performance of a manned expedition to the planet Mars.

Unlike the CIS, the RNS cannot be employed directly as an orbital injection stage.

RNS flight system definition studies have included both modular and large tank configurations. Figure B-6 illustrates a large tank configuration studied by the NR Space Division under contract to the NASA-MSFC. The single 33-foot-diameter tank accommodates 300,000 pounds of LH_2 with five percent ullage. With the NERVA engine delivering an average specific impulse of 775 seconds, the RNS can transport a payload of 175,000 pounds from its low earth operations orbit to a 90-nautical mile lunar polar orbit and return 15,000 pounds of payload to its earth operations orbit (Mode 1 operation). Approximately 50 percent of its outbound payload (82,000 pounds) will be LH_2 and LO_2 for use by the lunar landing tug.

An active docking system and supporting structure is incorporated in the forward skirt for docking to a propellant supply or maintenance element. A thrust structure with docking provisions is attached to the aft bulkhead for orbital installation or exchange of the NERVA engine. A supercritical storage O_2/H_2 reaction control system provides the vehicle with delta-V and three-axis control capability when the NERVA engine is not operating. The system is also used to provide roll control when the single NERVA engine is operating.

An artificial gravity field for propellant positioning using linear or radial acceleration is employed to facilitate refueling in orbit in the no-vent mode and can also be used with venting for conditioning of the tank and its contents.

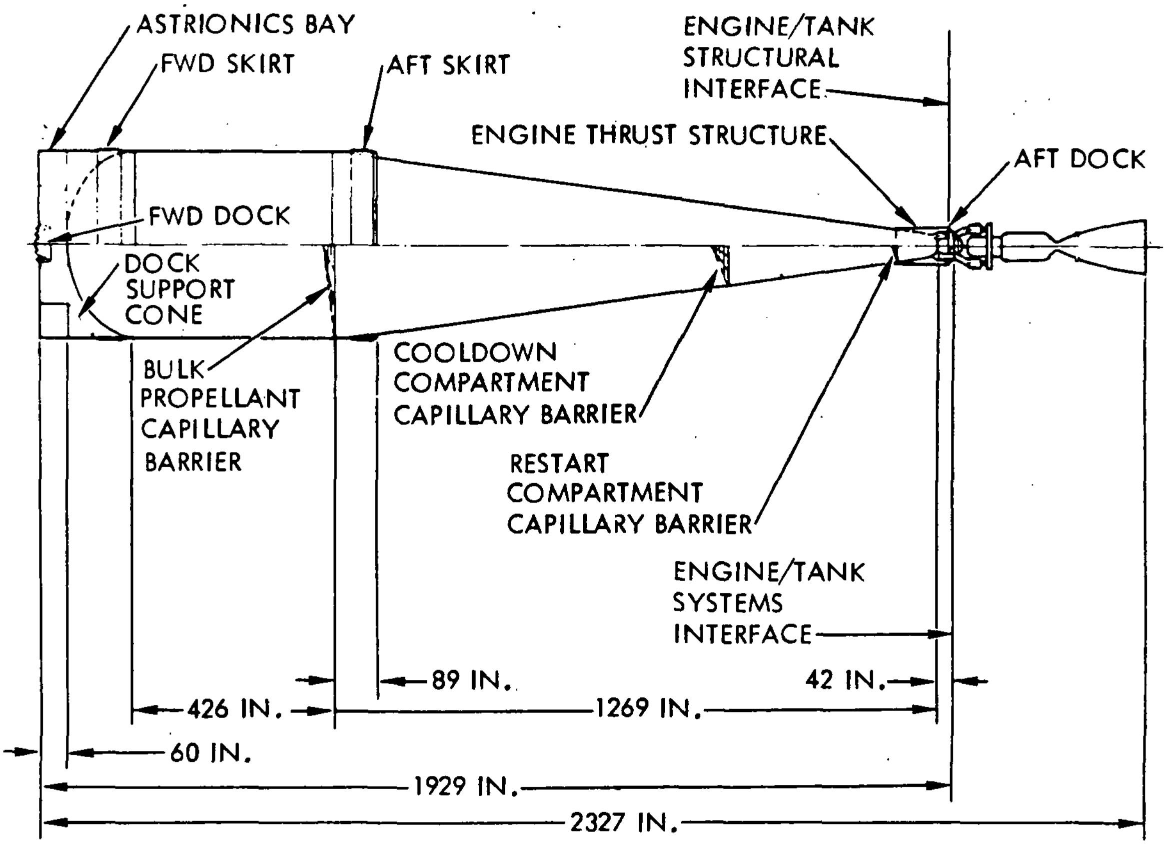
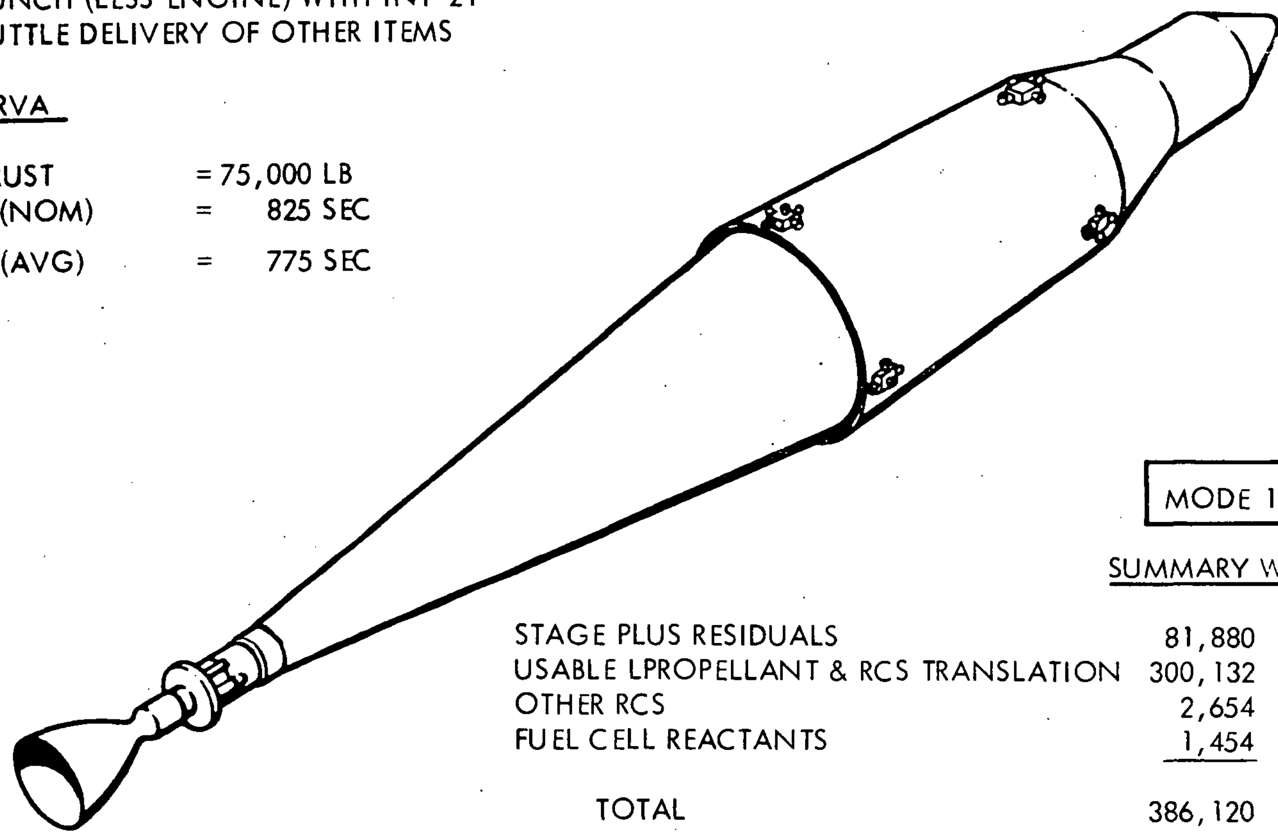


Figure B-6 Reusable Nuclear Shuttle Concept

33 FT DIA MAIN LH_2 TANK
1974 TECHNOLOGY; 3 YR OPER. LIFE OR 10 REUSES
LAUNCH (LESS ENGINE) WITH INT-21
SHUTTLE DELIVERY OF OTHER ITEMS

NERVA

THRUST = 75,000 LB
I_{sp} (NOM) = 825 SEC
I_{sp} (AVG) = 775 SEC



SUMMARY WEIGHT - LB		MODE 1	MODE 2
STAGE PLUS RESIDUALS		81,880	85,080
USABLE LPROPELLANT & RCS TRANSLATION		300,132	354,000
OTHER RCS		2,654	2,840
FUEL CELL REACTANTS		1,454	1,500
TOTAL		386,120	443,420
PAYLOAD:	OUTBOUND	175,000	320,000
	RETURN	15,000	16,800

Figure B-7 Single Tank RNS

Figure B-7 presents summary weight and performance data for RNS designs for two alternate flight modes. These have been designated Modes 1 and 2 in the CIS study; and the designations are retained herein. Mission Flight Mode 1 involves direct flight of a single-stage cislunar shuttle from a low earth parking orbit to a lunar parking orbit and a direct return flight to the low earth parking orbit after a stay in the lunar parking orbit. Mission Flight Mode 2 is an operational technique for reducing the delta-V required of the cislunar shuttle on the earth-return leg while retaining the Mode 1 flight plan on the outbound earth-moon leg. In Mode 2, the cislunar shuttle, upon approaching perigee, performs an insertion maneuver into a highly elliptical earth orbit. A space tug then performs a rendezvous with the cislunar shuttle and executes the circularization maneuver into low earth orbit. Mode 2 is more efficient than Mode 1 in that the propellants required to perform the circularization maneuver do not have to be transported from earth parking orbit to lunar parking orbit, and then be injected into the trans-earth leg.

In order to achieve the performance capability of 300,000 pounds of payload to lunar orbit and 30,000 pounds return to low earth orbit, the RNS for Mode 2 requires a 10 percent increase in LH_2 capacity. The added capacity may be achieved with an extension of about nine feet to the cylindrical section of the LH_2 tank.

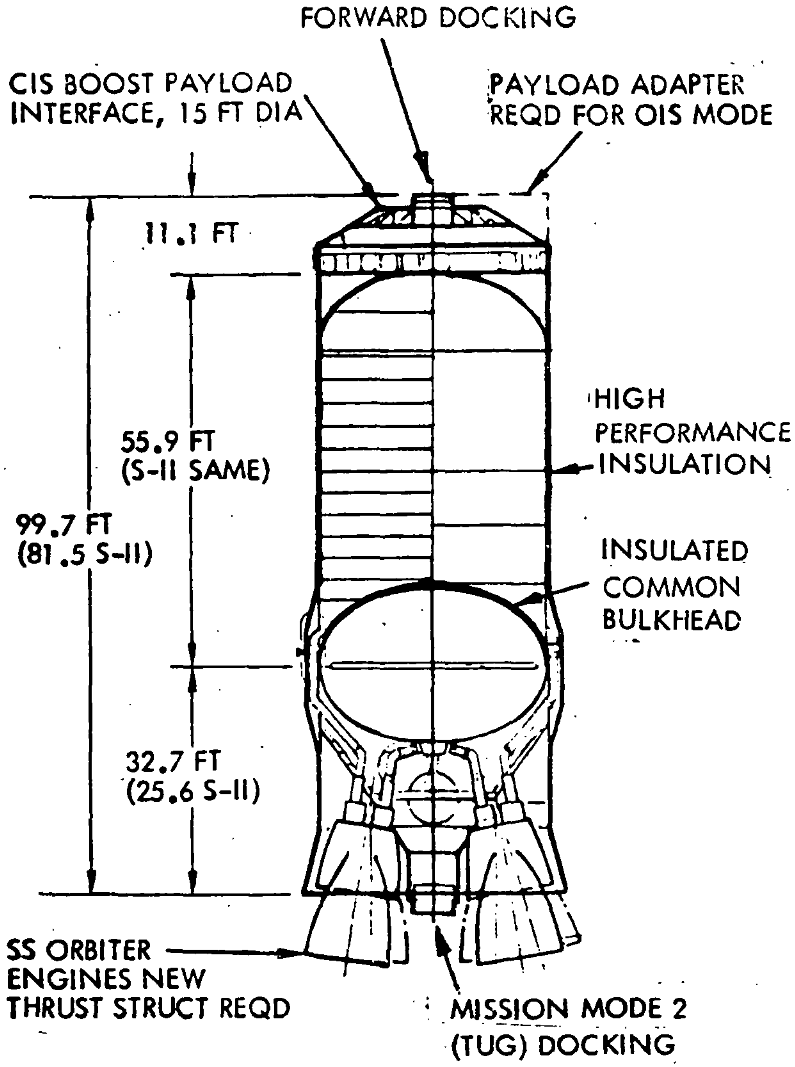
The Nuclear Shuttle Definition Study, Reference 3.3.1-1, utilized the minimum energy repeatable lunar mission as baseline for reference mission definition. The flight profile includes 108-hour translunar and transearth trip times and no lunar plane changes. These same repeatable, minimum-energy missions were incorporated in the "Identification of NASA Space Program Requirements" as specified in the ISPLS Guidelines and Constraints.

CHEMICAL INTERORBITAL SHUTTLE (CIS)

The CIS is a contemplated space-based reusable vehicle which is capable of transporting heavy payloads between low earth orbit and lunar or geosynchronous orbits and return. As such, it is an alternate to the reusable nuclear shuttle. Additionally, the CIS has the capability of injecting heavy payloads to earth orbit as an orbital insertion stage on the space shuttle booster.

Figure B-8 summarizes design, weight and performance characteristics of the CIS. The CIS is an S-II stage derivative design which is powered by two high chamber pressure orbiter engines. Payload performance is included for both Flight Modes 1 and 2.

The CIS lunar shuttle payload capability is based on the "S-II Stage Interorbital Shuttle Capability Analysis", performed under Change Order 2021 to Contract NAS7-200. The performance established during this analysis, Figure 3-35 in Reference 3.3.1-2, has been adjusted for propellant load variations and for zero lunar plane changes. However, the velocity increment change



* INCLUDES 79000 LBS TUG PROPELLANT

DESIGN

S-II SIZED TANKS
1974 TECHNOLOGY
3-YEAR OPERATING LIFE OR 10 REUSES
FORWARD & AFT DOCKING

MAIN PROPULSION

2 SHUTTLE ORBITER ENGINES
THRUST: 2 x 632,000 LB
I_{sp} = 460 $\pm$3 SEC @ MR OF 5.5:1

WEIGHTS	MODE 2	MODE 1
BURNOUT	128,626 LB	128,626 LB
PROPELLANTS	1,042,000 *	990,000
INITIAL	1,170,626 LB	1,018,626 LB

LUNAR SHUTTLE PERFORMANCE		
OUTBOUND	320,000 LB	175,000 LB
RETURN	16,800 LB	15,000 LB

Figure B-8 CIS Configuration "A"

in going from the CIS reference mission to the minimum energy mission (100 ft/sec total for the mission) has been neglected. The resulting CIS performance characteristics permit comparisons with the RNS in Mode 1 on a nearly equivalent basis. The three propellant loads shown in the payload capability graph (Figure B-9) represent the minimum necessary to meet the outbound and inbound payload requirements of the guidelines and constraints for the ISPLS study, a propellant load to produce the same payload capability as for the RNS at the study reference point, and a fully loaded vehicle.

Mechanical systems for the S-II stage-derivative CIS include propulsion, reaction control, propellant orientation, propellant transfer, etc. Two LO_2/LH_2 high-chamber pressure, variable-thrust shuttle orbiter engines are used for main propulsion. Two LO_2/LH_2 RL-10-type engines are used for orbital maneuvering. A supercritical storage O_2/H_2 system is employed for reaction control. The propellant orientation is accomplished by combining the functions of propulsive vent, propellant retention canopy, and reaction control system.

The propellant refill system utilizes single, axial, forward-end-docking with six-inch fill and four-inch vapor lines specified for the interface for each propellant system. Propellant transfer system lines interface within the stage docking ring and are routed to the respective propellant tanks. Within each tank, the transfer system terminates at two points - a spray ring and an open-ended fill and drain line.

REFERENCES

B-1 NHB 7100.5 January 1971 Edition, National Aeronautics and Space Administration, Launch Vehicle Estimating Factors for Use in Advanced Space Mission Planning

B-2 GDC-BNZ 70-024, General Dynamics Convair Aerospace Division, 30 December 1970, A Preliminary Investigation of Centaur/Shuttle Integration Report

B-3 SAMSO-TR-71-238, Final Report, Orbit-to-Orbit Shuttle (Chemical) Feasibility Study, October 1971

B-4 PD-71-114 Contract F04701-71-C-0171, 7 July 1971 Orbit-to-Orbit Shuttle (Chemical) Feasibility Study (OOS), Second Technical Direction Meeting Summary Briefing

B-5 "Pre-Phase A Study for an Analysis of a Reusable Space Tug," Final Report, North American Rockwell, Space Division Report SD71-292-3, March 22, 1971 (Contract NAS9-10925)

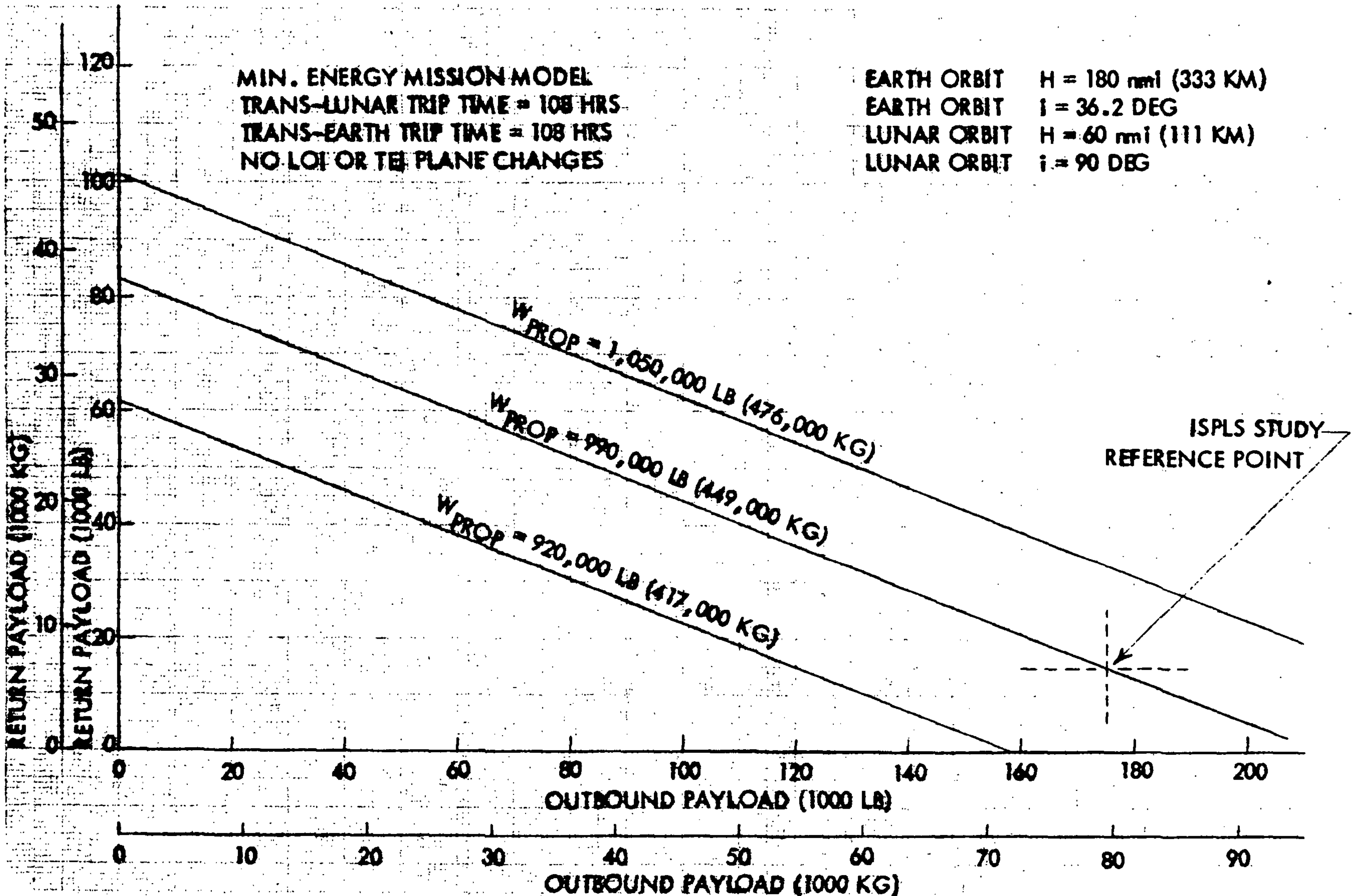


Figure B-9 CIS Lunar Shuttle Payload Capability

APPENDIX C. MAINTAINABILITY DESIGN CRITERIA

A. ACCESSIBILITY

- All access openings provided for the manipulation of units or components shall be located in a direct line with the equipment that requires access.
- Replaceable unit design shall permit direct visual and physical access with connectors and couplings for ease of removal/replacement.
- One large access is preferable to two or more small ones; but where structural or other considerations require, visual and physical access may be provided separately.
- Access considerations must make allowances for protective clothing.
- The hinge pin, in pin-type doors, must be readily accessible and easily removable.
- Access considerations must make allowances for the individual to see, feel, and manipulate components.
- Doors and access panels should allow for use in either vertical or horizontal positions.
- Locate individual servicing provisions and areas for easy and simultaneous access for both equipment and personnel. Consider horizontal, vertical, and mated configurations.
- Only a minimum number of latches should be used on panels where frequent access is required.
- Access openings need not be of regular geometric shape or size; however, the clearance necessary to perform maintenance must be considered with that work space required for easy passage of the items to be removed and replaced. The access shape and size selected shall provide adequate space for the technician to perform the desired maintenance/support action.
- All fluid and gas plumbing connections, test and service points, and electrical wiring connectors shall be immediately accessible from access openings.
- Fuses and circuit breakers shall be readily accessible during test/checkout functions.

- Major subsystem tanks, shelves, modules, and/or components shall be accessible at all sites, including in the launch pad configuration, for removal and replacement through access of one panel per bay.

- Accesses shall be designed and located to preclude damage to thermal insulation.

- On hinged access doors place the hinge on the bottom or provide a support so that the door will stay open without being held if unfastened in a normal installation.

B. STANDARDIZATION

- The quantities and types of mounting fasteners shall be standardized to minimize types of hand and power tools required to support operations.

- Hexagonal heads (socket) shall be used when appreciable torque is to be applied.

- Screw heads are suitable for low-torque applications.

- When mounting positions for similar parts or components must be different, design the variations into the mounts, rather than into the parts or components.

- Controls or switches causing movement of other devices should move in the same direction as the controlled device.

- Lever controls should move upward or to the right for an increase in function.

- Push-pull controls should be pulled for increase in function.

- Rotary controls should turn clockwise for increase in function.

- Toggle switches (when not directionally related to a controlled device) should be mounted vertically and should move upward for on, start, or increase.

- When mounting hardware, clamps and gaskets for components may be easily damaged or lost during component replacement, make such items a part of the component assembly so that such items will be furnished with replacement components.

C. SAFETY

- Subsystems and components shall be designed to minimize the likelihood of injury to operators from hardware failure; location/design shall minimize exposure of personnel to debris, shock, asphyxiation, radiation, etc.

- An equipment fail-safe design shall be provided where failure will disable the system or cause a catastrophe through damage to equipment, injury to personnel, or inadvertent operation of critical equipment.

- Units shall be so located and mounted that access to them can be achieved without danger to personnel from electrical charge, heat, moving parts, chemical contamination, pyrotechnic devices, and other harmful sources.

- Switches and controls which initiate hazardous operations (e.g., ignition, propellant transfer, etc.) shall require a locking control or device.

- Equipment shall be designed to prevent emission of flammable/ harmful vapors during operational or non-operational periods.

- Equipment causing personnel to be exposed to radiation hazards shall be safeguarded by shielding or other protective measures.

- Sharp edges and protrusions shall be avoided. If unavoidable, the projections shall be conspicuously marked or padded.

- Sensitive adjustments should be protected by guards, covers, or locking devices.

- Where feasible, electrical equipment shall be designed to be electrically isolated by interlocking switches or equivalent before physical access to exposed hazardous connections and compartments is possible.

- Electrical wiring shall be routed through plugs and connectors to preclude the removal of a plug or connector causing exposure or hot leads.

- Any plumbing and tubing for liquid, gas, steam, etc., shall be be clearly and unambiguously marked as to the contents, pressure, temperature, and any specific hazardous properties.

- Colors for identifying equipment and conditions shall be used to guard against inadvertent operation of, or accidental contact with, equipment which may result in injury or damage.

- GSE will be designed so that potential hazardous or dangerous areas, e.g., electrical, mechanical, or fluid, shall not be a safety constraint when the GSE is being maintained, repaired, installed, calibrated, etc.

- Design for maximum practical clearances and fits on all mating parts, and specify maximum possible wear limits.

- Connectors shall be provided with aligning pins or other alignment devices. Alignment pins shall project beyond electrical pins.

- Connectors shall be designed so that it is impossible to insert the wrong plug in a receptacle.

- Connectors shall be located far enough apart to grasp firmly for connection/disconnection.

- Whenever feasible, connectors requiring no more than one turn, or other quick-disconnect plugs, shall be used.

- Controls and displays (types) shall be standardized to minimize excessive quantities of varied switches, gages, knobs, and other controls.

- Internal access doors shall be standardized, when feasible, for size, shape, and fasteners, including hinges.

- Modules/components and related plumbing shall have a standardized minimum space or distance between brazed connections to permit use of brazing/debrazing tools.

- Standardize and minimize types of lubricating fluids for all systems to avoid filling and servicing errors and to minimize logistics support costs.

D. INTERCHANGEABILITY

- Assemblies, components, and parts shall be capable of being readily installed, removed or replaced without alteration, misalignment, or damage to the item being installed or to adjoining parts.

- Individual parts will be capable of performing all of the functions established by design requirements and the assembly of the mating parts will not require operations such as prying, cutting, drilling, bending or forcing.

- Commonality should be emphasized in the selection of power supplies and connectors.

- External and internal access doors, panels, plates, and access covers being utilized for similar purposes, in two or more places, shall be interchangeable wherever feasible.

- Utilize filters that can be interchangeable wherever possible.

- Utilize interchangeable parts to minimize different types and quantities of parts.

- Switches, dials, handles, knobs, decals, labels, and placards used in two or more similar applications shall be interchangeable.

E. MOUNTING

- Components shall be mounted in accessible areas to preclude blind adjustments or checkout.
- Large components shall be mounted in such a location so they will not obstruct access to other modules/components.
- Where feasible, units shall be mounted as modules in an orderly array on a two-dimensional surface and shall not be stacked one on another.
- Plumbing joints and connections shall be brazed except where mechanical connections are approved.
- Module/component plumbing, including related fittings, shall be routed in locations that preclude stepping/kicking damage, or use as hand holds.
- Units shall be mounted so that maintenance points; e.g., checkout, test, service, etc., are accessible and face access openings.
- Module/component and housing mounting fasteners (e.g., bolts, screws) shall be held to a minimum to preclude excessive maintenance time.
- Units shall be mounted so that removal/installation shall occur along a straight or slightly curved line rather than through an angle.
- Guides or tracks shall be provided to assist in positioning and aligning module/component installation or replacement.
- Module/components housing, if required, shall be removable from the unit rather than require that unit be removed from the housing.
- Modules/components requiring housing to be removed for test, checkout, inspection or servicing, shall be immediately accessible from access openings.
- High flow system lines shall have quick disconnects to preclude personnel injury and equipment damage by whipping of lines in event of failure or breakage.
- Control and display panel plumbing and wiring shall be designed with maximum extension capability to provide panel removal without disconnection of any connector to permit accessibility behind panels.

- Modules/components shall be mounted on trays/shelves to provide a sliding/roll-out accessibility feature for equipment maintenance and repair functions.

F. LIFTING AND ATTACHMENT POINTS

- Large, bulky, or heavy modules/components shall have hoist or lifting attachment points and shall be clearly identified.
- Modules/components weighing ten pounds or more shall have handles or otherwise lifting/attach points to preclude unit handling by delicate parts.
- Design handles to be used for other purposes, such as protecting equipment.
- Provide supports, guides, and guide pins to assist in aligning and positioning units.
- Hard-points shall be provided for handling large components and allowance shall be made for standard ground shock, vibration environment, and for more severe handling, if possible.
- Lifting, handling, and attachment features shall be an integral design requirement, including drawing notation of "special handling care", if required, which obviously should be minimized.

G. LABELLING, CODING, AND MARKING

- Labels shall appear either on or immediately below the item to be identified. The labels shall be located to preclude association of a label with the wrong item.
- Use red background for maintenance warning labels or placards.
- Labels shall be brief. Although the nomenclature should clearly indicate the function being displayed or controlled, similar names should be avoided. Abbreviations, where required, shall be common and nonambiguous.
- Label all test points and indicate the tolerance limits which should be measured at each point.
- Provide schematics and instructions for all units which may require trouble-shooting. If possible, attach placards directly to unit chassis. Next preferable location is to attach to unit cover or housing.
- Lettering shall be in capitals in preference to lower case lettering.

- Fluid lines shall be marked to indicate the fluid medium, the design operating pressure, and the direction of fluid flow.

- Markings shall be provided as necessary to warn personnel of hazardous conditions and precautions.

- Labeling/marking material must not deteriorate and must be firmly secured.

- Instruction plates shall be securely fastened to enclosures or instrument panels, and shall be placed in a position where they can be easily read.

- Lifting units shall be conspicuously stenciled to indicate the maximum lifting capacity of the equipment.

- Mark "No Step" areas, as appropriate, near walkways to any service points or where fragile or delicate equipment might be damaged.

- Mark electrical wiring with wire number, system identification, wire size, and voltage.

- Abstract symbols (squares, Greek alphabet letters, etc.) shall not be used. Percent signs, plus signs, etc., are acceptable.

- Labels shall be etched or embossed into the component or chassis rather than merely printed or stamped on the surface. If surface labels must be used, decals, silk screened, or stamped labels are preferable.

- Labels shall be placed where they can be seen when all the equipment is installed. Schematics, if required, should be provided on external plates if at all possible.

- All access openings, panels, doors, covers, and plates or adjacent areas shall clearly be marked or labeled for ready recognition of the access's intended utilization.

H. PACKAGING

- Modular assemblies requiring test and checkout functions shall be packaged to provide maximum accessibility to the test and checkout points.

- Modular assemblies will incorporate brazed connections to ensure system/component reliability.

- Subsystem modules shall incorporate provisions that will provide ease of disconnection, removal, and replacement of major assemblies or components through use of modular construction design principles with ready access for disconnecting interfacing plumbing, electrical wiring, and control cables.

- Interfacing plumbing will incorporate appropriate mechanical-type connections; e.g., B-nuts, to facilitate installation, removal, and/or replacement of the modules/components.

- Module plumbing and electrical wiring shall be packaged to preclude damage by pinching, bumping, or mashing during installation.

- GSE units shall be designed to have modularized drawers/shelves with a sliding/rolling capability to enhance removal/replacement, test, and checkout functions.

- External handles, gages, switches, controls, etc., on GSE units shall be designed, whenever feasible, flush with the unit's surface.

I. WORK SPACE

- Wherever possible, design for maintenance in a standing position. Allow space for change of posture if prolonged kneeling, bending, or crouching is required.

- Provide adequate illumination and communications in all compartments and major work areas. Install inter-phone system jacks at key work locations.

- Provide safety belt tether points for work positions where personnel are vulnerable to falling.

- Include provisions for purging all tanks and compartments prior to entry by personnel, and for ventilating tanks, compartments, and recesses during occupancy by technicans performing maintenance.

- Provide space, shelves, hooks, or other features as necessary for test equipment, tools, and lights that may be required for maintenance.

- Work space shall be properly located and oriented to allow the technician to perform functions related to or involved in the specific activity.

- Work space shall be sufficiently strong structurally to withstand the technician's and his equipment's weight and shall be large enough for him to accomplish his tasks safely and efficiently.

- Do not allow covers, doors, or panels to obstruct vital work space when open.

- Provide foot holes, steps, and non-skid surfaces or coatings as necessary to protect personnel from slipping or falling.

- Shelf assemblies shall be installed in such a manner that adequate space exists between the two shelves to permit required technician activity; e.g., maintenance, inspection, removal, repair, etc.

J. ELECTRICAL WIRING AND COMPONENT CRITERIA

- Cable runs shall be suitably enclosed or otherwise protected to minimize hazards to the crew and provide adequate mechanical protection for the conductors.
- Where feasible, electrical equipment shall be designed to be electrically isolated by interlocking switches or equivalent before physical access to exposed hazardous connections and compartments is possible.
- Where possible, electrical and electronic devices shall incorporate protection against reverse polarity and/or other credible improper electrical inputs during checkout tests.
- Umbilical connectors shall be sufficiently rugged to withstand numerous matings and de-matings without exceeding "normal acceptable" wear. The definition of "normal acceptable" wear shall be specified on engineering drawings and specifications.
- Connectors shall be designed (clocked, routed, coded, etc.) to minimize the possibility of cross and mis-mating, particularly after final assembly.
- Wire harnesses shall be designed to permit at least one repair/replacement of a connector(s) without replacing the harness.
- All electrical connections shall be made so that vibration, expansion, contraction, or relative movement shall not break the connection nor loosen it to such an extent that the resistance of the connection will vary under such conditions.
- Cables and wire bundles shall be routed and installed in locations to preclude damage by personnel walking/kicking, using as hand holds, pinching by doors, covers, etc.
- Connectors and connections shall have adequate spacing between them to enhance finger-operation removal/installation of individual items from modules/panels.
- Connectors shall have recessed pins to preclude pin damage during maintenance operations.
- Means should be provided to protect electrical/electronic equipment from fluid contamination.

APPENDIX D.

SPECIAL INSTRUCTIONS FOR RED TEAM OPERATIONS[1]

OPERATIONAL READINESS:

A. All Red Crew members are expected to provide and have instantly available:

1. Non-spark producing shoes
2. Long-sleeved, flame retardant, pocketless coveralls, nomex or equal
3. Hard hat with chin strap
4. OIS headset
5. Personal tool kit (if a technician)

B. Prior to a Red Crew operation the following steps must be taken to safe the space vehicle for Red Crew entry. All spacecraft and launch vehicle test conductors must comply and verify to the launch vehicle test supervisor that the following steps have been accomplished:

1. Launch vehicle propellant dispersion systems safed (electrically and mechanically) and the terminal count sequencer key in possession of the LCC system safety supervisor (CPSS).
2. Spacecraft pyro busses and logic busses safed and the keys in possession of the spacecraft pad leader.
3. All propellant flow terminated. Under special conditions, S-IVB slow LOX fill might be initiated with the Red Crew still at the pad. However, the pad leader or Red Crew chief shall be notified prior to initiation of S-IVB LOX slow fill.
4. Space vehicle propellant and pneumatic systems in a stable condition.

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[1] From TCPV-30029, R13, "S-II Stage and GSE Supplementary Operations for Space Vehicle Countdown Demonstration Test and Launch Countdown," M020, North American Rockwell, July 13, 1971.

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5. Controlled switching in effect while personnel are within the blast danger area.

6. No computer test programs entered during the time personnel are within the blast danger area.

7. Vehicle and GSE hazardous gas monitor system operational and indicating safe conditions.

C. If during a Red Crew operation one or more of the following contingencies arise, the Red Crew will immediately clear the pad:

1. A severe electrical storm in the area (within a five-mile radius of the pad).

2. Serious cryogenic propellant leak in line, heat exchanger, etc., on mobile launcher and/or pad apron.

3. Loss of vacuum in a cryogenic propellant heat exchanger or lines leading to rapid pressure increase.

4. Fire indication in space vehicle or mobile launcher.

5. Hypergolic propellant leaks as determined by systems safety supervisor.

6. Malfunction or failure of one of the RCA-110A computers.

7. Out of tolerance leakage of the common bulkhead LO_2/LH_2 propellant tanks as determined by C2PV from system vacuum measurements.

8. Flight battery malfunction (excessive current or temperature of a nature that would preclude safe replacement) (CD only)

9. Anytime unforeseen conditions arise, at the discretion of the system safety supervisor, test supervisor, launch vehicle test conductor, S-II test conductor, S-II pad leader or KSC system safety.

PROCEDURE FOR RED CREW STAGE ENTRY AND EGRESS:

A. The credible contingencies that may occur in the aft interstage are:

1. Engine component malfunction inspection

2. Replacement of a discrepant battery if battery temperatures are readable and within safe tolerances as determined by constant monitoring of battery temperatures by C2NP. If battery temperature has started to increase for no apparent reason, or is no longer readable due to recorder/meter being

pegged out, no battery replacement will be attempted. Replacement of battery will be considered only if temperatures become readable and decreasing. (This sequence for CD only.)

3. Thermal control diaphragm inspection or repair.

4. Loose electrical connector to a system component.

5. Flight control component malfunction inspection.

B. The credible contingencies that may occur in the forward skirt are:

1. Safe and arm device manual safing.

2. Hydrogen tank vent valve actuation system inspection.

3. Forward barrier seal inspection.

C. The following list of required equipment and personnel is basic and will be available to support the operation:

1. Four auxiliary breathing units with communication capability and one hour air supply. These will be hardline breathing masks with breathing air K-bottles on LUT. These units will also be equipped with backup mini-bottles in the event of hardline failure.

2. One portable OIS box and cable.

3. Two 50-foot life lines, steel cable with chafe guard.

4. Long-sleeve coveralls and gloves.

5. Four flashlights and two spot lights, explosion proof, with tethers.

6. Two heat shield quarter panel splice bridges, Standard 608.

NOTE: With the A7-84 heat shield protective set not installed, personnel must not approach closer than 30 inches to the heat shield quarter panel splices, unless the Standard 608 bridges are installed.

7. One set of safing pins for the forward carrier plate.

D. Ingress to the forward skirt area will encounter a low-temperature environment that may hinder an individual's ability to do productive work. Low temperature in itself may not prove detrimental to the task but in combination with poor access, limited visibility, and restricted mobility, it must be considered.

E. Since a Red Crew entry could require personnel to perform tasks on or near hardware/systems that are conveying cryogenic liquids, they should be aware of the hazards of cryogenic temperatures. Do not allow any bare skin or unprotected part of the body to touch frosted components, fittings or other hardware that is frosted. Doing so will cause a severe burn. First aid for frost bite or burns consists of copious amounts of water and medical treatment. Do not work under uninsulated lines/components. If an inspection or work required must be performed below and near cryogenic hardware, perform tasks on the upwind side. Performing work on the downwind side would cause a face shield to fog-up and impair visibility. Delicate tissue, such as the eyes, can be damaged by exposure to these cold gases which may be too brief to affect the skin of the hands and face.

F. The following personnel protective equipment will be worn when working on/around any lines or vessels that have recently contained or presently contain cryogenic liquids:

1. A face shield extending below the chin and around to the side of the face and worn either directly on the head or attached to the hard hat.

2. Gauntlet-type, loose fitting, asbestos gloves or leather of the same type.

3. Non-static producing, flame retardant, long-sleeved, cuffless coveralls; non-sparking (no protruding nails), non-porous shoes.

G. Since gaseous oxygen is odorless and will permeate and be retained in the clothing, do not smoke or get near anyone that is smoking. Do not use any spark producing device or get near a source of ignition for at least thirty (30) minutes after being exposed to, or working in, an oxygen enriched atmosphere and then only after your clothing has been aired completely. An oxygen meter will be used to determine if too much oxygen is present. The main point to remember is that materials that don't burn or are hard to ignite (such as flame retardant coveralls) will burn furiously in an oxygen rich atmosphere.

H. During a Red Crew entry, LH_2 system preconditioning can be in progress. Any entry required in the area of the LH_2 systems should be sniffer-checked for leaks by KSC Safety prior to performing any tasks.

I. In addition to the general safety precautions already discussed, always anticipate the probability of a fire associated with small leaks in the LH_2 system; never use your hand to find a leak as GH_2 fires are normally invisible. In the area of the A7-71, do not stand under or near uninsulated fill or vent valves carrying cryogenic cooled GH_2.

J. When the Red Crew leaves the pad area and subject to the approval of KSC system safety supervisor, the space vehicle may be reconfigured for flight by performing the following or removing the following restrictions:

1. Allow switch action.

2. Repressurize launch vehicle propellant tanks and pneumatic tanks to applicable pressures, if required.

3. Computer test programs may be performed.

4. The TCS key will be returned to the operational station if required and the launch and spacecraft propellant dispersion systems and pyro busses reconfigured to the applicable T-hour configuration.

APPENDIX E

CLUSTERED PAYLOADS ANALYSIS

A clustered payloads analysis was performed and compared with other earth-to-orbit logistics concepts to determine its feasibility. The results indicate that shuttle flights can be reduced by 40% and on-orbit propellants reduced by 30% using clustering. These results are based on the five space program levels of activity developed in this study.

In order to establish the feasibility of clustering, a shuttle utilization analysis was first performed on a simple logistics system concept to establish a reference point for subsequent comparisons. This system hypothesized the separate and individual shuttle delivery of payloads to orbiting upper stages and the subsequent delivery of propellants to those stages also on an individual basis using the shuttle. This concept implies that upper stages are space-based and require propellant transfer on orbit. Propellant is loaded into a shuttle cargo-bay tank and delivered to orbit where it is transferred to an upper stage. This concept results in unacceptably poor utilization of shuttle capacity and consequently large numbers of shuttle flights required to support a given level of space effort. It is recognized that no logistics system would be operated this inefficiently, but it does provide a reference point for minimum shuttle utilization.

A more effective approach introduces increased complexity by combining a payload, its upper stage, and the required propellant quantity (within the stage) on a single shuttle flight. This will significantly reduce the number of shuttle flights from those of the initial concept.

The analysis of these two concepts for program level C are summarized in Figures E-1, -2 and -3. The results indicate a low shuttle weight and volumetric utilization. Cargo bay volumetric utilization increases from 20% to 80% and weight utilization increases from 5% to about 75% for all missions in a typical year - 1985. For all 12 years of program level C, as indicated in Figure E-3, the shuttle cargo bay weight utilization averages 65% for science payloads and upper stages launched together. The corresponding cargo bay length utilization is similar. From this analysis it is concluded that even payload-plus-upper-stage, or one-to-one (one payload to one upper stage) loading of the cargo bay is not sufficiently effective, at 65% utilization, to preclude more sophisticated concepts.

Additional reduction is possible, at the price of increased complexity, by combining multiple mission payloads and propellants on a single shuttle flight. This method, called clustering, usually requires payload repackaging for optimum loading. A comprehensive analysis of this concept was made as it seemed most likely to minimize the amount of propellants required on-orbit. The following ground rules were defined for this analysis.

1. Only payloads launched in the same year are considered.
2. Only payloads launched to approximately the same orbital inclination are considered.

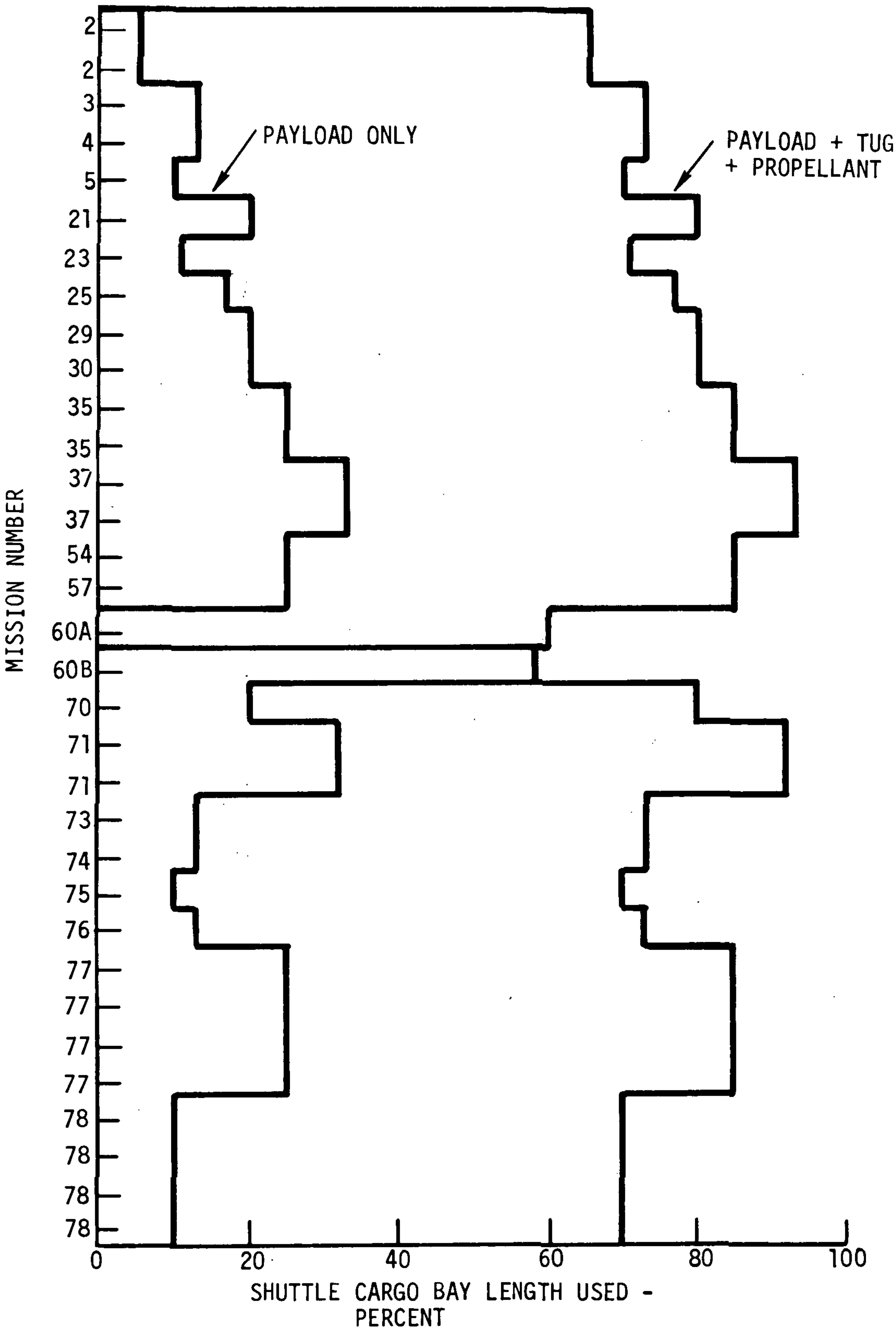


Figure E-1 Shuttle Cargo Length Utilization Program Level C - 1985

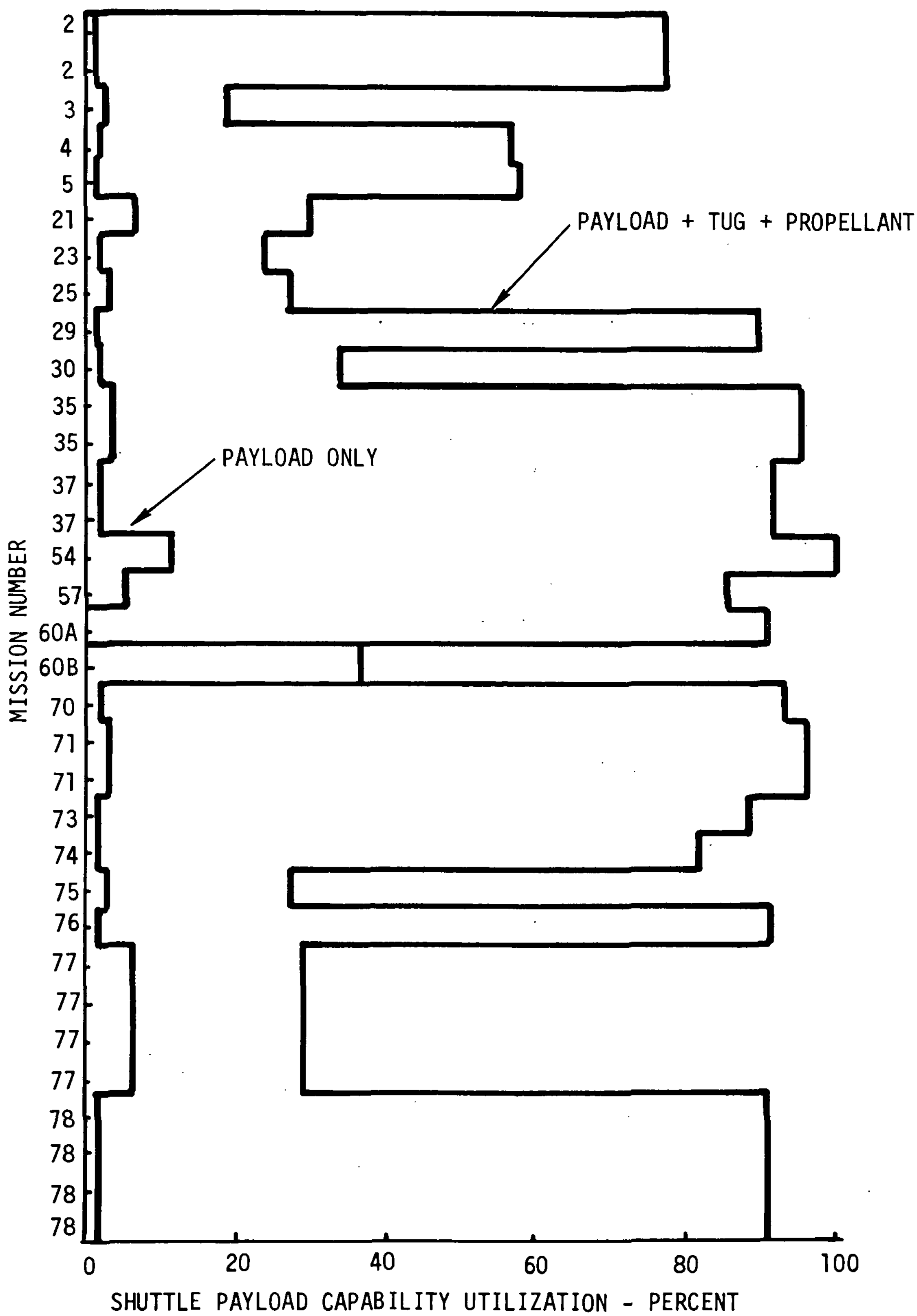


Figure E-2 Shuttle Cargo Weight Utilization
Program Level C - 1985

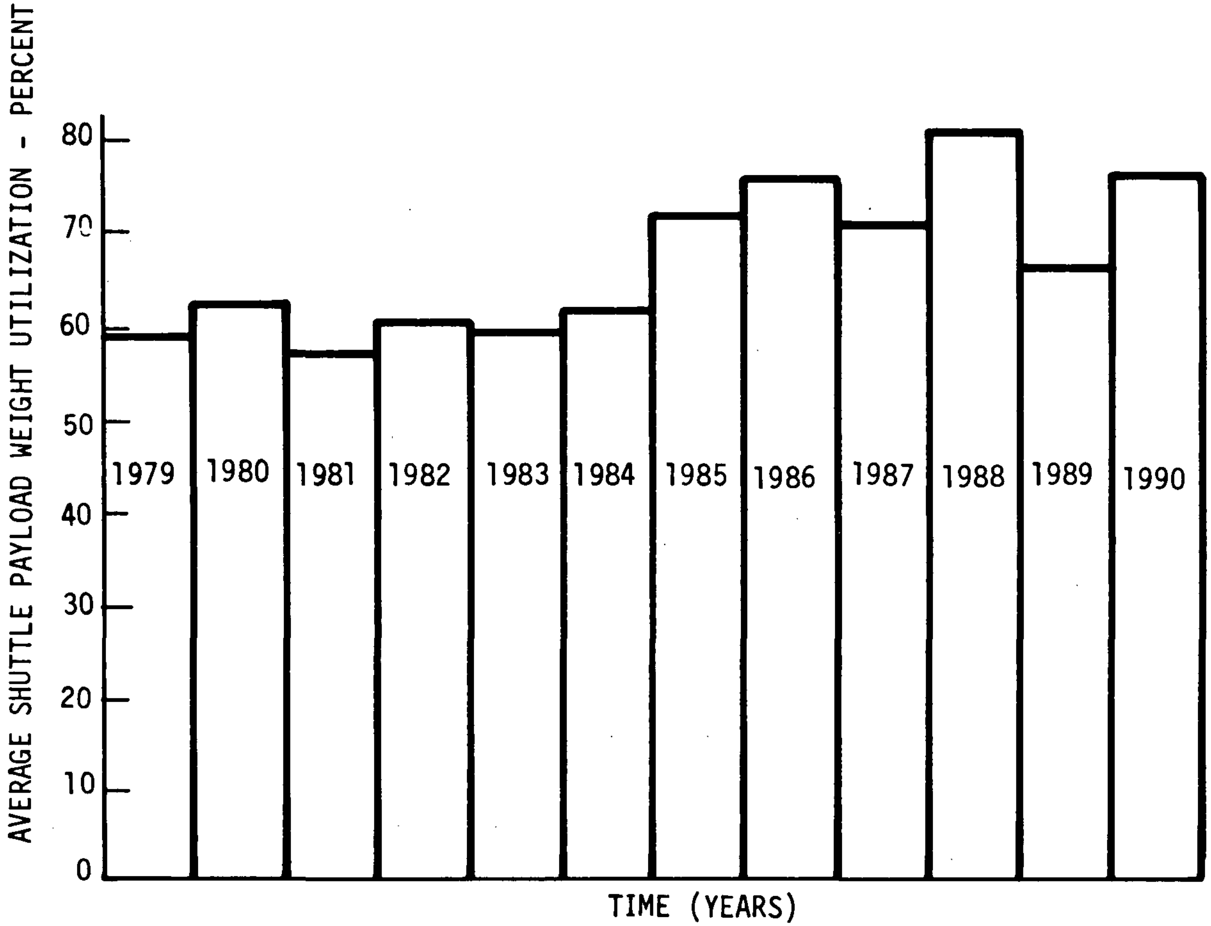


Figure E-3 Shuttle Payload Weight Utilization
Program Level C

3. The clustered payloads and their propulsive upper stage must not exceed shuttle cargo constraints.

4. Mission durations for the upper stage must not exceed the shuttle mission duration requirement.

5. Payloads can be repackaged to optimum shuttle cargo bay dimensions but a 25% volumetric penalty must be added.

6. Payloads can be clustered in any orientation on the upper stage but no orbital assembly or fueling is to be required.

7. Up and down missions can be combined on one flight.

8. Shuttle abort propellants can be utilized on-orbit.

9. Shuttle or support crew constraints are not included.

10. Center of gravity effects are not included.

11. Propellant losses are not included.

A nominal clustered-payload mission as analyzed here is illustrated in Figure E-4 and consists of the shuttle delivering a ground-based payload propulsive stage and a group of payloads to a common or near-common orbital inclination. The payloads are usually destined for widely different altitudes. According to a previously defined and carefully optimized mission plan, the PPS departs the shuttle and transports each of the payloads to the desired orbital inclination and altitude, separates from it at that point and proceeds to the remaining orbits. When all payloads have been delivered, recoverable PPS such as the Centaur GT and ground-based tug will return to the shuttle. In some high-energy missions the PPS will not have sufficient propellant to return to the shuttle and therefore must be expended. In a few instances it is possible for the orbiter itself to deliver more than one payload directly to its desired orbit without the need for an upper stage.

An example of a clustered payload mission analysis is given in Figure E-5. Five polar and near-polar orbit satellites scheduled in program Level C, 1981, would require five shuttle launches and 10,752 pounds of cryogenic propellants for five flights of the Centaur GT to place them in their respective orbits.

The potential benefits of clustering these payloads into a single mission, in terms of the reduction in shuttle flights and propellants consumed, were analyzed as illustrated in Figure E-6. To determine the propellant requirements for this mission, all the flight maneuvers of the PPS must be defined. The characteristic velocities determined for each maneuver, the point for payload release established, and the propellant calculated for each maneuver. The total propellant is the sum of the individual maneuver propellants. For the mission presented, twelve separate burns are required. The total propellants required are given for three PPS configurations in Figure E-6. Maximum shuttle

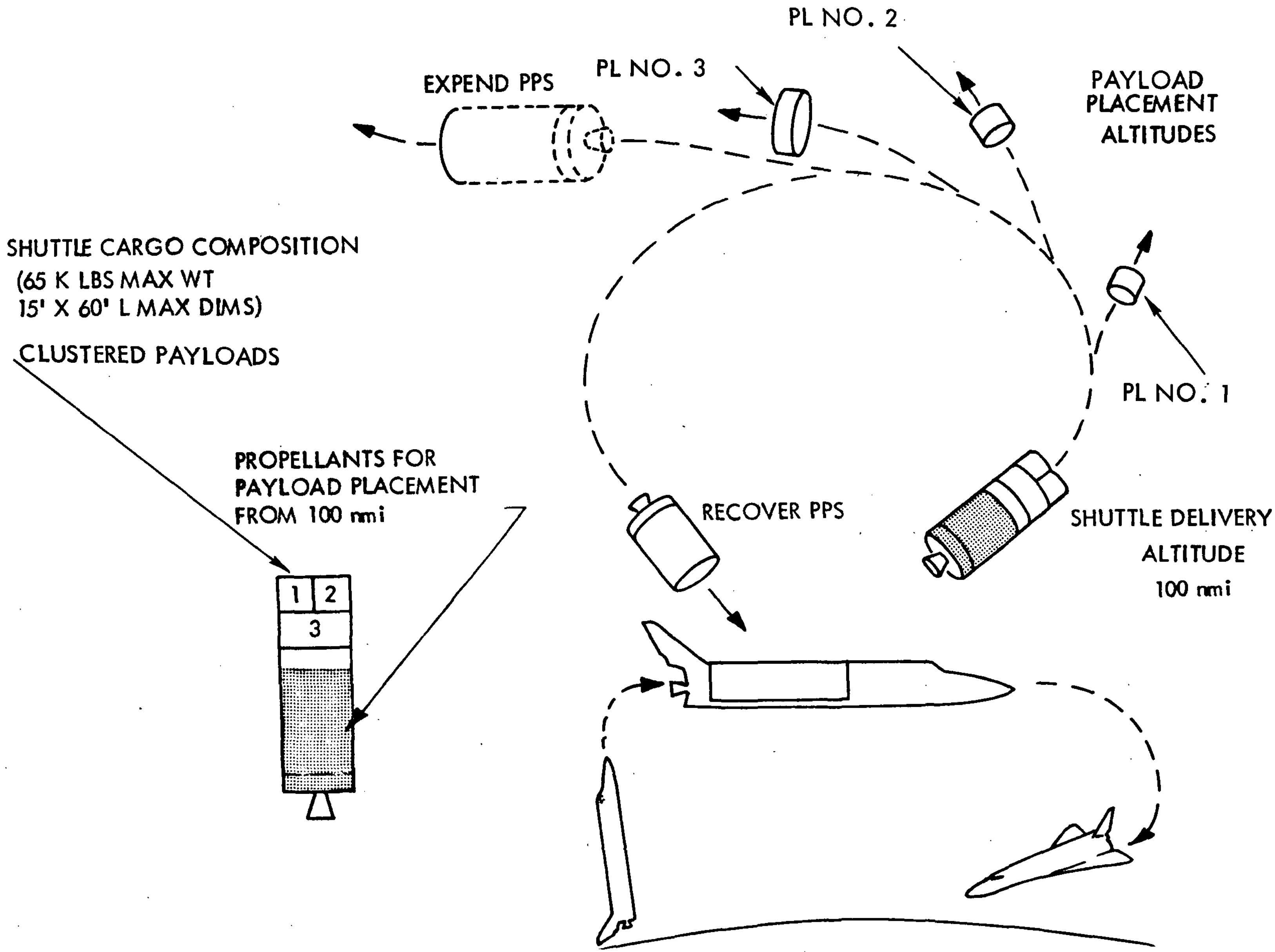


Figure E-4 Nominal Clustered Mission

MISSION	PAYLOAD	DIA	LENGTH	INCL.	ALT (nmi)	PROPELLANT	SHUTTLE FLTS
21	POLAR EARTH OBS	6	12	99.15	500	1462	1
23	EARTH PHYSICS	3.5	6.5	90	400	941	1
25	TIROS	5	10	100.7	700	1937	1
30	SMALL APPLICATIONS	6.5	12	90	300 x 3000	4375	1
75	TOS METEOROLOGICAL	5	6	100.7	700	1987	1
						10752 LBS	5

TYPICAL CARGO BAY CONFIGURATION

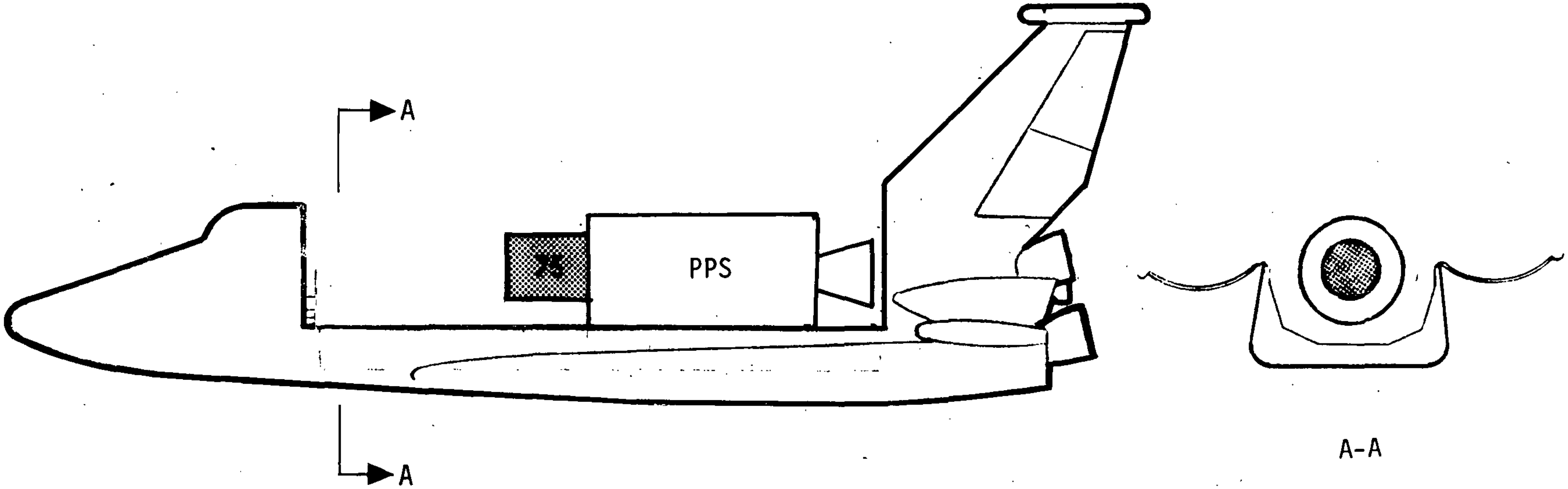
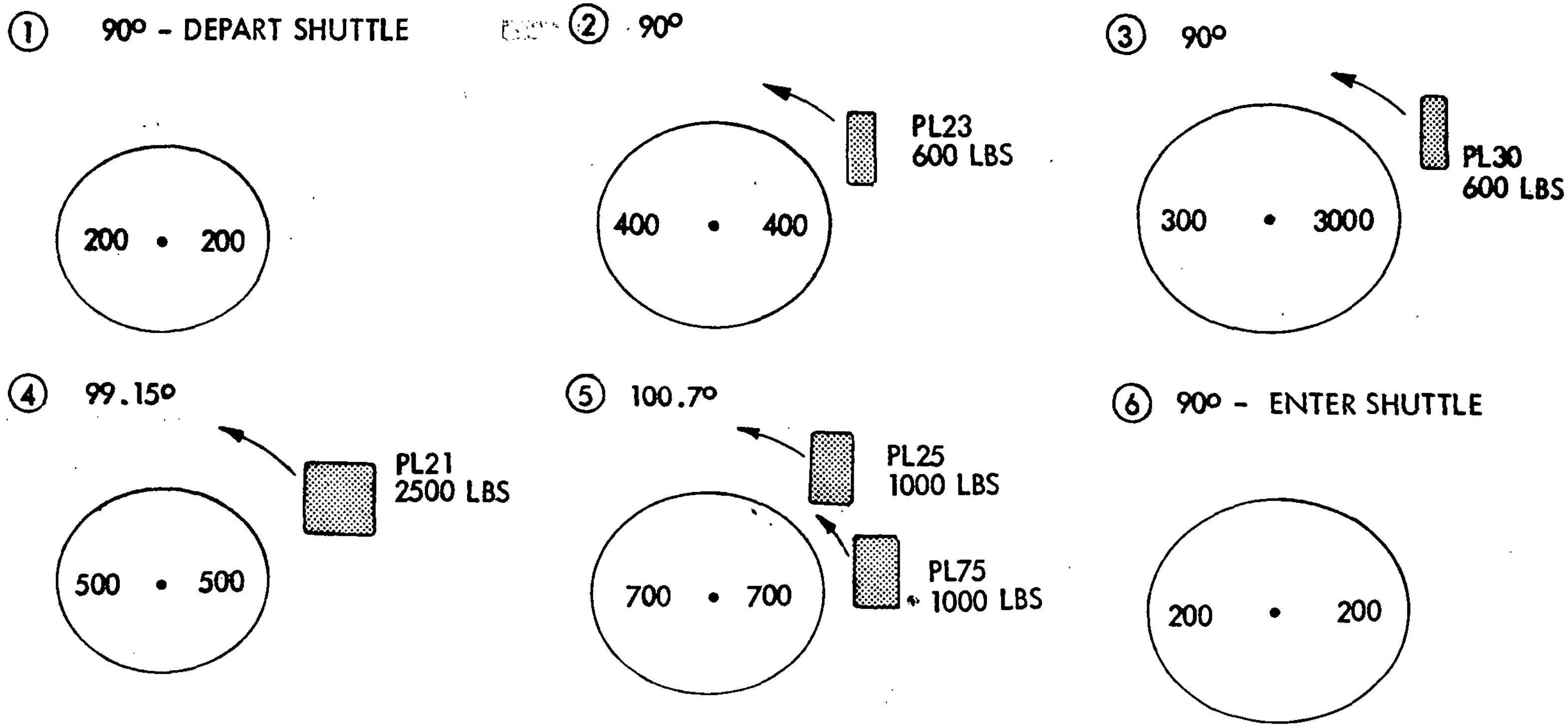


Figure E-5 Non-Clustered Payload Mission

SD72-SA-0053-2



VEHICLE	ΔV + (PAD)	W_{PL}	W_{BO}	W_G*	W_P	$W_{P\ MAX}$
ITS	18359 (1.1)	5700	5250	40000	26318	29050
GB TUG	18359 (1.1)	5700	7270	40000	25605	27030
SB TUG	17500 (1.05)	5700	10201	40000	25173**	24099**

* MAX SHUTTLE CAPABILITY TO 90° X 200 X 200

** MISSION PROPELLANT EXCEEDS CAPACITY

Figure E-6 Clustering Mission Analysis

capability of 40,000 pounds to polar orbit limits the available propellant as shown. For this mission the space-based tug is shuttle-limited and cannot be used to transport all five payloads. The results are summarized in Figure E-7 which compares the one-to-one concept with the clustering concept. An 80% reduction in shuttle flights is achieved at an increase in PPS propellants of 15,500 pounds. About 1200 other mission combinations were examined and the predominant clustering mission actually results in a decrease of propellants over the baseline concept because of fewer plane changes. Although the propellants have increased on this mission, they can still be accommodated along with the PPS and five payloads to polar orbit on a single shuttle flight.

Traffic models were developed for clustered-payload missions for all five program levels. These models represent a sequence of equally spaced shuttle launches designed to deliver all the payloads to the desired orbit at minimum total program cost. This cost includes shuttle flights, PPS flights, and orbital propellant weights. The model for program level C is presented in Table E-1 at the end of this Appendix.

The results of this analysis are given in Figure E-8 which compares two earth-to-orbit traffic models, each based on use of a ground-based PPS as the upper stage. The "baseline" concept is the one-to-one concept described earlier and it is compared with the clustered-payload concept. Figure E-8 shows, for example in program level C, that 141 fewer shuttle flights and 3,217,000 pounds less on-orbit propellants are necessary with clustering. Slightly offsetting this is the result that three more upper stages need to be expended. Figure E-9 gives the yearly breakdown of differences between the concepts for program level C and shows the amounts to average 270,000 pounds of propellants and 12 shuttle flights each year.

While these savings are impressive there are some costs which are not treated here. Multiple-shuttle payloads must be identified and planned well in advance of the launch to assure successful placement. A typical mission might require a single upper stage to place two or three payloads in separate earth orbits with different altitudes and inclinations. Optimized shuttle utilization means that each placement mission will be difficult from a performance standpoint because each upper stage will be utilized to its maximum capabilities. Thus, mission requirements will determine the sequence of payload placement, their assembly positions within the shuttle cargo bay, and repackaging of current payloads into standardized and/or preselected shapes.

Preferred shapes include cylinders with a diameter either equal to the maximum cargo bay diameter or less than half the maximum to permit side-by-side payload installations. Disk-shaped payloads with diameter equal to the maximum will permit end-to-end stacking and docking of adjacent payloads. The possibility of standardized or preferred shapes will have to be confirmed with the scientific community, particularly with respect to long focal length optical, IR, and UV telescopes. Standardized shapes, particularly for the smaller payloads, would greatly simplify the integration problem.

Ground support equipment and facilities will also incur additional costs due to the need for processing multiple payloads simultaneously rather than on an individual basis.

PAYLOAD	DIA.	LENGTH	INCL.	ALT	PROPELLANT	SHUTTLE FLT
23 + 30 + 21 + 25 + 75	12.5	18.5	90 - 100.7	30 - 3000	26318 LBS	1

CARGO BAY CONFIGURATION

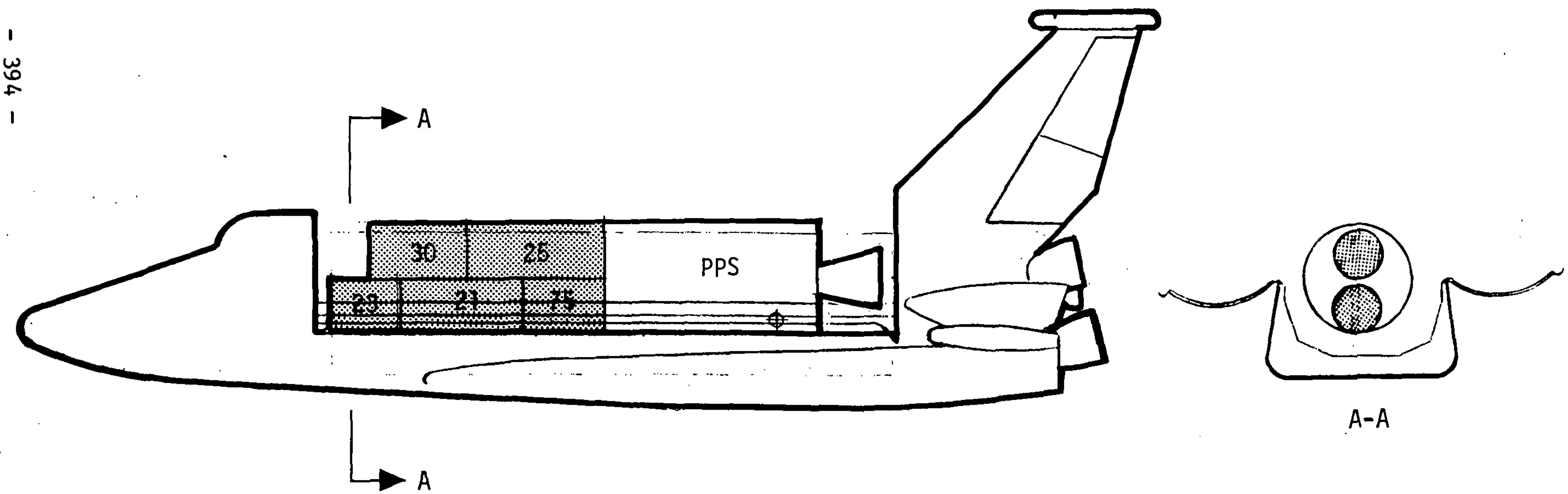


Figure E-7 Clustered Payload Mission

SD72-SA-0053-2

	PROGRAM LEVEL				
	A	B	C	D	E
BASELINE** - SHUTTLE FLIGHTS	180	237	327	484/574*	523/634*
CLUSTERED SHUTTLE FLIGHTS	102	123	186	381/471	420/531
CLUSTERED SHUTTLE FLIGHT REDUCTION	78	114	141	103/103	103/103
BASELINE PROPELLANT WEIGHT (K LBS)	3198	7605	10077	15464/22364	16279/25110
CLUSTERED PROPELLANT WEIGHT (K LBS)	2298	4257	6860	13064/19964	13879/22710
CLUSTERED PROPELLANT WEIGHT REDUCTION (K LBS)	900	3448	3217	2400/2400	2400/2400
BASELINE PPS EXPENDED	21	9	19	18	22
CLUSTERED PPS EXPENDED	21	7	22	18	22

*RNS/CIS

** BASELINE = ONE PAYLOAD PER SHUTTLE FLIGHT CONCEPT

Figure E-8 Traffic Model Summary

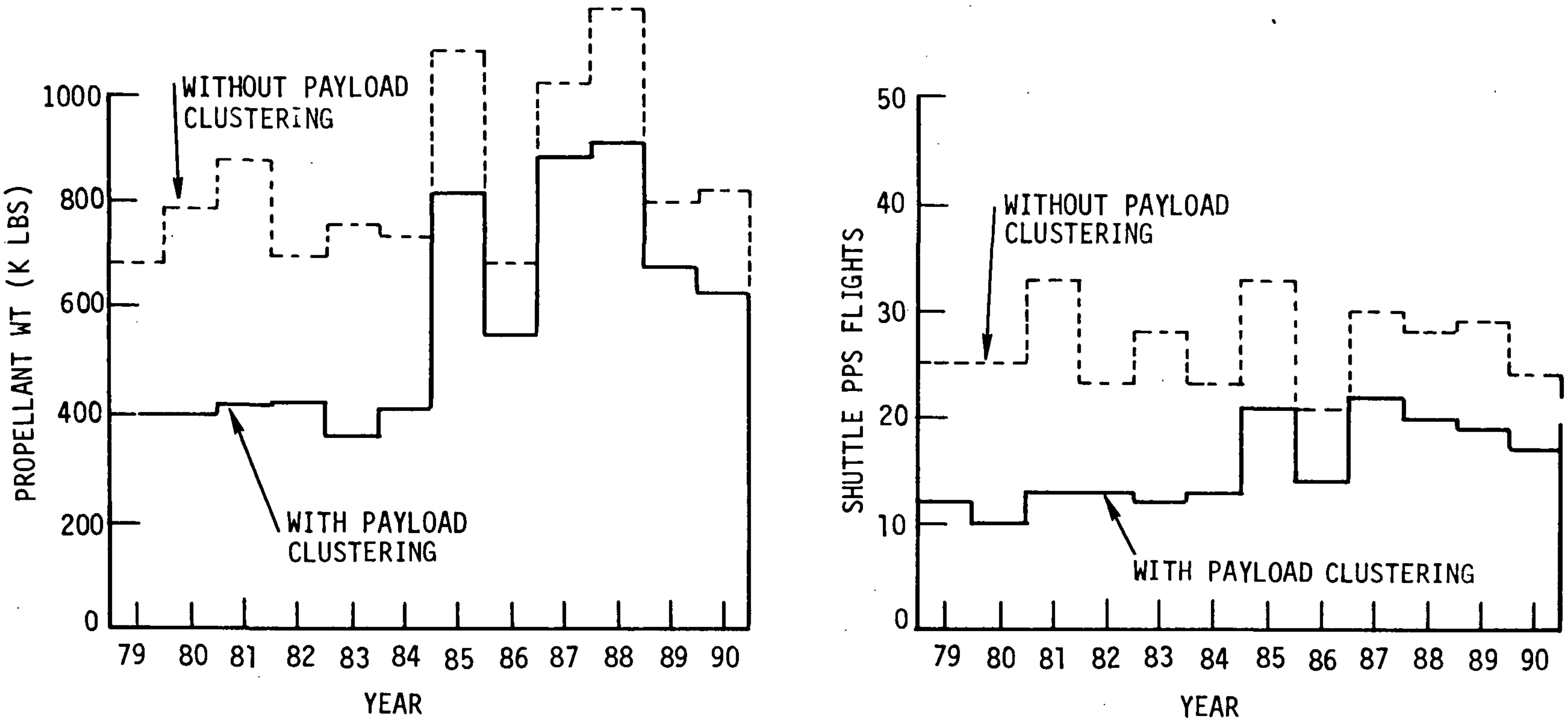


Figure E-9 Reduction in Shuttle Flights and Propellants Due to Clustering
Program Level C

Table E-1 Propellant Logistics Traffic Model*

This model lists the sequence of shuttle flights in each year for a clustered payload mission concept. The identification (by mission No.), combined length, and gross weight of the payloads and the PPS are given together with the mission propellant required for the placement by the PPS and the inclination of the payload's orbit. This model delivers all program level C placements.

Flt	Payload	L (FT)	W_G (LBS)	W_P (LBS)	i (DEG)	Notes
C-1-79	1 + 43	39.5	5020	0	28.5	Shuttle only
C-2-79	1 + 48	39.5	13720	0	28.5	Shuttle only
C-3-79	3+4+5	22	2800		0	GT expended
	GT	32.8	46687	41437		
		54.8	49487			
C-4-79	13	34	19700	0	30	
C-5-79	21+30+75	27 R	4100			
	GT	32.8	31352	26042	90/100.7	
		59.8	35452			
C-6-79	28	20	7950		0	GT expended
	GT	32.8	31109	25859		
		52.8	39059			
C-7-79	29+31	24	1420		0	
	GT	32.8	48850	43600		
		56.8	50270			
C-8-79	33+33	24 R	4000		0	1.05 ΔV
	GT	3 .8	50100	44850		
		56.8	54100			
C-10-79	37+37	22 R	2000		0	
	GT	32.8	49950	44700		
		54.8	51950			
C-11-79	70+70	24	2840		0	1.05 ΔV
	GT	32.8	48300	43050		
		56.8	51140			
C-12-79	71+76	27	3145		0	1.05 ΔV
	GT	32.8	48800	43550		
		59.8	51945			
C-13-79	73+73+73	24	2100		29	
		32.8	50250	45000		
		56.8	53250			

*Based on NR Phase B Shuttle, GD Centaur GT from 1979-1984, and NR Ground-Based Tug from 1985-1990.

SS = Side by side payload assembly in cargo bay
R = Repackaged payload to fit in cargo bay

Flt	Payload	L (FT)	W_G (LBS)	W_P (LBS)	i (DEG)	Notes
C-14-79	77+77	24 R	5000		99.15	
	GT	37.8	6988	1738		
		56.8	11988			
C-15-79	77+77	24 R	5000		99.15	
	GT	32.8	6988	1738		
		56.8	11988			
C-9-79	36	15	2300		0	1.05 V
	GT	32.8	45829	40579		
		47.8	48129			

Flt	Payload	L (FT)	W_G (LBS)	W_P (LBS)	i (DEG)	Notes
C-1-80	2+2+72+72 GT	15.5 SS[1] 32.8 48.3	3440 44680 48120	 39430	28.5	
C-2-80	3+4+5 GT	22 32.8 54.8	2800 47500 50300	 42243	28.5	
C-3-80	6+14	23	5400	0	30	
C-4-80	14	13	3500	0	30	
C-5-80	21+23+ 30+75 GT	18.5 SS 32.8 51.3	4700 31352 36052	 26092	90	23 not on GT
C-6-80	34+34 GT	21R[2] 32.8 53.8	4290 49600 53890	 44350	0	1.05 V
C-7-80	22+29+37 GT	27R 32.8 59.8	2600 46500 49100	 41250	0	1.05 V
C-8-80	42	37	6000	0	28.5	
C-9-80	44	37	5700	0	28.5	
C-10-80	44	37	5700	0	28.5	
C-11-80	45	37	7100	0	28.5	
C-12-80	46	37	5000	0	28.5	
C-13-80	49	37	3800	0	28.5	
C-14-80	52 GT	12 32.8 44.8	1700 43078 44778	 37828	30	
C-15-80	70+74+76 GT	26R 32.8 58.8	3120 47500 50620	42250	5° 10°	

Flt	Payload	L (FT)	W_G (LBS)	W_P (LBS)	i (DEG)	Notes
C-16-80	71+71	21R	4290	44250	0	1.05 ΔV
	GT	32.8	49500			
		53.8	53790			
C-17-80	36+36	24R	4290	44250	0	1.05 ΔV
	GT	32.8	49500			
		56.8	53790			
C-18-80	73	8	700		29	
	GT	32.8	46252	41002		
		40.8	46952			

Flt	Payload	L (FT)	W_G (LBS)	W_P (LBS)	i (DEG)	Notes
C-1-81	1+15			0	28.5 X 270 X 350	
C-2-81	2 GT	3.5 32.8 36.3	720 40048 40768	34798	28.5	
C-3-81	3+4+5 GT	22 32.8 54.8	2800 47500 50300	42243	55	1.1 ΔV
C-4-81	8 GT	5 32.8 37.8	500 29194 29694	23944	28.5	
C-5-81	9 GT	15 32.8 47.8	6000 49407 55407	44157	28.5	1.05 ΔV
C-6-81	14	13	3500	0	30	Revisit
C-7-81	14	13	3500	0	30	Revisit
C-8-81	21+23+25 +30+75 GT	18.5SS 37.8 51.3	5700 31042 36742	25792	90-100.7	
C-9-81	27+28+76 GT	26RSS 32.8 58.8	9950 35050 45000	29800	0	Expended Must expend to do 28 so just added others
C-10-81	29+36+70 +74 GT	24 37.8 56.8	5020 47590 52610	42340	0	1.05 ΔV
C-11-81	35+35 GT	24R 32.8 56.8	4000 45690 49690	40440	0	1.05 ΔV
C-12-81	38				0	
C-13-81	38				0	
C-14-81	38				0	
C-15-81	30				0	
C-16-81	42				0	
C-17-81	44				0	

Flt	Payload	L (FT)	W_G (LBS)	W_P (LBS)	i (DEG)	Notes
C-18-81	44			0		
C-19-81	47			0		
C-20-81	50			0		
C-21-81	61			0		
C-22-81	62+62			0		
C-23-81	62+62			0		
C-24-81	62+63			0		
C-25-81	66			0		
C-26-81	67			0		
C-27-81	71 GT	19 32.8 51.8	2145 50170 52315	44920	0	
C-28-81	6-72's GT	12 32.8 44.8	6000 49180 55180	43930	28.5	No repack 1-1 [illegible] V
C-29-81	73+73 GT	8 32.8 40.8	1400 48950 50350	43700	29	
C-30-81	77+77 GT	24R 32.8 56.8	5000 6988 11988	1738	99	
C-31-81	77+77 GT	24R 32.8 56.8	5000 6988 11988	1738	99	

Flt	Payload	L (FT)	W_G (LBS)	W_P (LBS)	i (DEG)	Notes
C-1-82	1+1+72+72 GT	14.5^{SS} 32.8 47.3	3440 42280 45720	 37030	28.5	72's by GT
C-2-82	3+4 GT	16 37.8 48.8	2200 33862 36062	 28612	90	
C-3-82	5+30+32 GT	18 32.8 50.8	2020 36627 38647	 31377	90	
C-4-82	13+14	59	24500	0	30	
C-5-82	14+16 GT	13 32.8 45.8	3500 7090 10590	 1840	28.5/30	
C-6-82	16+44	50	9200	0	28.5	
C-7-82	21+23+75 GT	24.5 32.8 57.3	4100 26579 30679	 21329	90-99- 100.7	
C-8-82	22+24+27 +27+29 GT	18 32.8 50.8	4600 50250 54850	 45000	 0	100% F @ 1.050 ΔV
C-9-82	35+35 GT	24R 32.8 56.8	4000 45690 49690	 40440	0	1.05 ΔV
C-10-82	38	54	27500	0	55	
C-11-82	38	54	27500	0	55	
C-12-82	38	54	27500	0	55	
C-13-82	39	51	27500	0	65	
C-14-82	39	51	30000	0	65	
C-15-82	39	51	30000	0	65	
C-16-82	42	37	6000	0	90	
C-17-82	42	37	6000	0	90	
C-18-82	44	37	5700	0	28.5	

Flt	Payload	L (FT)	W_G (LBS)	W_P (LBS)	i (DEG)	Notes
C-19-82	53 GT	12 32.8 44.8	7900 46478 54388	41238	30	Planetary 1.0 ΔV Recovered
C-20-82	55 GT	15 32.8 47.8	900 34369 35269	29119	30	GT expended Planetary
C-21-82	55 GT	15 32.8 47.8	900 34369 35269	29119	30	Planetary GT expended
C-22-82	GT	32.8	50250	45000	30	1 booster for C-23-82
C-23-82	60 GT	20R 32.8 52.8	24000 30650 54650	25400	30	2 GT's expended Planetary W_P = 70400 lbs
C-24-82	63	30	20000	0	55	
C-25-82	63	30	20000	0	55	
C-26-82	63	30	20000	0	55	
C-27-82	63	30	20000	0	55	
C-28-82	63	30	20000	0	55	
C-29-82	63	30	20000	0	55	
C-30-82	71+62 GT	27 32.8 59.8	33145 51400 54545	46150	0	1.05 ΔV

Flt	Payload	L (FT)	W_G (LBS)	W_P (LBS)	i (DEG)	Notes
C-1-83	1+1+72+72 GT	14.5^{SS} 32.8 47.3	3440 42280 45720	37030	28.5	72's only on GT
C-2-83	3+4+5 GT	22 32.8 54.8	2800 46687 49487	41437	0	Expended
C-3-83	13+14	47U- 13D	23.2U- 3.5D	0	30	
C-4-83	14+16 GT	13 32.8 45.8	3500 7090 10590	1840	28.5/30	Up + dn
C-5-83	16+44	50	9200	0	28.5	
C-6-83	17	54	27000	0	30	
C-7-83	21+23+ 30+75 GT	18.5^{SS} 32.8 51.3	4700 31352 36052	26092	90-99- 100.7	EOS drops 23 @ 90^{o} X 400
C-8-83	24+70+ 70+74 GT	$22R^{SS}$ 32.8 54.8	4540 50250 54790	45000	0	1.05 ΔV
C-9-83	27+28+76 GT	$26R^{SS}$ 32.8 58.8	9950 35050 45000	29800	0	GT expended
C-10-83	29+35+35 GT	27 32.8 59.8	4600 50250 54850	45000	0	1.05 ΔV
C-11-83	36+36 GT	24 32.8 56.8	4000 50250 54850	45000	0	1.05 ΔV
C-12-83	38	54	27500	0		
C-13-83	38	54	27500	0		
C-14-83	38	54	27500	0		
C-15-83	38	54	27000	0		
C-16-83	39	51	30000	0		

Flt	Payload	L (FT)	W_G (LBS)	W_P (LBS)	i (DEG)	Notes
C-17-83	39	51	30000	0		
C-18-83	44+16	50	9200	0	28.5	44-200 X 200 16-350 X350
C-19-83	45	37	7100	0		
C-20-83	63	30	20000	0		
C-21-83	63	30	20000	0		
C-22-83	63	30	20000	0		
C-23-83	63	30	20000	0		
C-24-83	63	30	20000	0		
C-25-83	63	30	20000	0		
C-26-83	64+66	32U, 58D	22KU, 33KD	0		
C-27-83	67+68	38U, 45D	19KU 25KD	0		
C-28-83	71+71 GT	21R 32.8 53.8	4290 49500 53790	 44250	0	1.05 ΔV
C-29-83	73 GT	8	700		29	
C-30-83	77+77 GT	24R 32.8 56.8	5000 6988 11988	 1738	99.15	
C-31-83	77+77 GT	24R 32.8 56.8	5000 6988 11988	 1738 359927	99.15	

Flt	Payload	L (FT)	W_G (LBS)	W_P (LBS)	i (DEG)	Notes
C-1-84	1+2 GT	5.8 32.8 38.6	1440 40043 41488	34798	28.5	
C-2-84	3+4+5 GT	22 32.8 54.8	2800 47500 50300	42243	28.5	
C-3-84	7	7	1500	0	85	
C-4-84	10 GT	12 32.8 44.8	1900 41750 43450	36300	28.5	19.3
C-5-84	11 GT	12 32.8 44.8	1900 31058 32958	25808	28.5	1 AU
C-6-84	14+16+18 GT	13 32.8 45.8	3500 7170 10670	1920	28.5/30	GT for PC only + 1 PC for 3 missions
C-7-84	14+16+18 GT	13 32.8 45.8	3500 7170 10670	1920	28.5/30	"
C-8-84	21+30+75 GT	27R 32.8 59.8	4100 31352 35452	26092	90/100.7	
C-9-84	22+28+70 +76 GT	27R 32.8 59.8	11370 37850 49220	32600	0	GT expended Excess L
C-10-84	29+35+35 GT	27 32.8 59.8	4600 50250 54850	45000	0	1.05 ΔV
C-11-84	31+36+37 GT	27 32.8 59.8	4120 48700 52820	43450	0	1.05 ΔV
C-12-84	38	54	27500	0		
C-13-84	38	54	27500	0		
C-14-84	38	54	27500	0		
C-15-84	38	54	27500	0		
C-16-84	39	51	30000	0		

Flt	Payload	L (FT)	W_G (LBS)	W_P (LBS)	i (DEG)	Notes
C-17-84	39	51	30000	0		
C-18-84	39	51	30000	0		
C-19-84	40	54	29500	0		
C-20-84	41	51	22500	0		
C-21-84	41	51	22500	0		
C-22-84	GT	32.8	50250	45000	30	1 booster for C-22-84
C-23-84	59 GT	20R 32.8 52.8	27000 34050 61050	 28800	30	2 GT's expended Planetary W_P = 73800
C-24-84	61	40	2000	0		
C-25-84	63	30	20000	0		
C-26-84	63	30	20000	0		
C-27-84	63	30	20000	0		
C-28-84	63	30	20000	0		
C-29-84	63	30	20000	0		
C-30-84	63	30	20000	0		
C-31-84	71+71 GT	21R 32.8 53.8	4290 49500 53790	 44250	0	1.05 V

FLIGHT	PAYLOAD	W_G (LBS)	W_P (LBS)
C-85-13	38	27,500	
C-85-14	38	27,500	
C-85-15	38	27,500	
C-85-16	39	30,000	
C-85-17	39	30,000	
C-85-18	40	29,500	
C-85-19	40	29,500	
C-85-20	40	29,500	
C-85-21	41	22,500	
C-85-22	41	22,500	
C-85-23	54	65,168	50,600
C-85-24	60 Comet Rendezvous Payload	24,000	
C-85-25E	60 Tug for C-85-24	58,800	51,550
C-85-26	61	20,000	
C-85-27	62	20,000	
C-85-28	62	20,000	
C-85-29	62	20,000	
C-85-30	63	20,000	
C-85-31	63	20,000	
C-85-32	63	20,000	
C-85-33	63	20,000	
C-85-34	63	20,000	
C-85-35	63	20,000	
C-85-36	66	33,000	

FLIGHT	PAYLOAD	W_G (LBS)	W_P (LBS)
C-85-37	67 Earth Obs. Lab, Placement 68 Comm/Nav. Lab-Retrieval	25,000	
C-85-38	70	60,412	51,722
C-85-39	71	62,432	53,017
C-85-40	71	62,432	53,017
C-85-41	73	57,151	49,181
C-85-42	74	52,847	44,877
C-85-43	77 77	14,330	2,060
C-85-44	77 77	14,330	2,060
C-85-45	78 78	62,100	52,830
C-85-46	78 78	62,100	52,830
C-86-1	1 16	4,220	
C-86-2	1 16	4,220	
C-86-3	3 4	37,400	27,930
C-86-4	5 30	40,000	31,530
C-86-5	14	3,500	
C-86-6	14 76	62,742	50,972
C-86-7	18	3,500	
C-86-8	18	3,500	

FLIGHT	PAYLOAD	W_G (LBS)	W_P (LBS)
C-86-9	20	3,500	
C-86-10	20	3,500	
C-86-11	21 26 26	17,100	2,330
C-86-12	22 29	60,970	52,100
C-86-13E	28	42,413	27,193
C-86-14	35	62,028	52,758
C-86-15	35	62,028	52,758
C-86-16	39	30,000	
C-86-17	39	30,000	
C-86-18	39	30,000	
C-86-19	40	29,500	
C-86-20	40	29,500	
C-86-21	40	29,500	
C-86-22	40	29,500	
C-86-23	41	22,500	
C-86-24	41	22,500	
C-86-25E	58	62,777	51,807
C-86-26	61	20,000	
C-86-27	61	20,000	
C-86-28	61	20,000	
C-86-29	63	20,000	
C-86-30	63	20,000	
C-86-31	63	20,000	
C-86-32	63	20,000	

FLIGHT	PAYLOAD	W_G (LBS)	W_P (LBS)
C-86-33	63	20,000	
C-86-34	63	20,000	
C-86-35	63	20,000	
C-86-36	63	20,000	
C-86-37	71	62,432	53,017
C-86-38	71	62,432	53,017
C-86-39	72 72	53,300	44,030
C-86-40	72 72	53,300	44,030
C-86-41	75	10,790	2,520
C-87-1	1 16	4,220	
C-87-2	2 16	53,500	42,000
C-87-3	3	43,120	34,650
C-87-4	4	39,070	30,800
C-87-5	5	50,470	42,600
C-87-6	8 14	40,600	29,320
C-87-7	13 18	24,500	
C-87-8	14 76	62,742	50,972
C-87-9	18	3,500	
C-87-10	20	3,500	
C-87-11	20	3,500	
C-87-12	21 26 26	17,100	2,330

FLIGHT	PAYLOAD	W_G (LBS)	W_P (LBS)
C-87-13	23 30	14,065	5,595
C-87-14	26 26 75	17,240	3,970
C-87-15	27 29	60,970	52,100
C-87-16	35	62,028	52,758
C-87-17	35	62,028	52,758
C-87-18	36	62,864	53,294
C-87-19	36	62,864	53,294
C-87-20	40	29,500	
C-87-21	40	29,500	
C-87-22	40	29,500	
C-87-23	40	29,500	
C-87-24	40	29,500	
C-87-25	41	22,500	
C-87-26	41	22,500	
C-87-27E	57	55,034	44,464
C-87-28	61	20,000	
C-87-29	61	20,000	
C-87-30	63	20,000	
C-87-31	63	20,000	
C-87-31	63	20,000	
C-87-33	63	20,000	
C-87-34	63	20,000	
C-87-35	63	20,000	
C-87-36	63	20,000	
C-87-37	63	20,000	

FLIGHT	PAYLOAD	W_G (LBS)	W_P (LBS)
C-87-38	71	62,432	53,017
C-87-39	71	62,431	53,017
C-87-40	72 72	53,300	44,030
C-87-41	72 72	53,300	44,030
C-87-42	72	50,685	42,415
C-87-43	73	57,151	49,181
C-87-44	74	52,847	44,877
C-88-1	1 16	4,220	
C-88-2	1 18	4,220	
C-88-3	3 4 5	61,220	51,150
C-88-4	12 14	60,000	45,715
C-88-5	12 14	60,000	45,715
C-88-6	16 22	62,770	51,000
C-88-7	17 17	27,000	
C-88-8	20 27	62,742	50,972
C-88-9	20 27	62,742	50,972
C-88-10	21 75	14,485	3,715
C-88-11E	28	42,413	27,193
C-88-12	29 76	61,000	52,130

FLIGHT	PAYLOAD	W_G (LBS)	W_P (LBS)
C-88-13	30	13,422	5,552
C-88-14	35	62,028	52,758
C-88-15	35	62,028	52,758
C-88-16	36	62,864	53,294
C-88-17	39	30,000	
C-88-18	39	30,000	
C-88-19	39	30,000	
C-88-20	40	29,500	
C-88-21	40	29,500	
C-88-22	40	29,500	
C-88-23	40	29,500	
C-88-24	41	22,500	
C-88-25	41	22,500	
C-88-26	54	65,000	50,600
C-88-27	63	20,000	
C-88-28	63	20,000	
C-88-28	63	20,000	
C-88-30	63	20,000	
C-88-31	63	20,000	
C-88-32	63	20,000	
C-88-33	63	20,000	
C-88-34	63	20,000	
C-88-35	64 65	30,000	
C-88-36	70 70	64,300	54,200
C-88-37	71	62,432	53,017
C-88-38	71	62,432	53,017

FLIGHT	PAYLOAD	W_G (LBS)	W_P (LBS)
C-88-39	72 72	53,300	44,030
C-88-40	78 78	62,100	52,830
C-88-41	78 78	62,100	52,830
C-89-1	1 16	4,220	
C-89-2	1 16	4,220	
C-89-3	3 4 5	61,220	51,150
C-89-4	10 14	55,894	43,224
C-89-5	11 14	43,700	31,030
C-89-6	13	21,000	
C-89-7	18	3,500	
C-89-8	18	3,500	
C-89-9	20	3,500	
C-89-10	20	3,500	
C-89-11	21 75	14,485	3,715
C-89-12	23 30 32	15,145	5,855
C-89-13E	28	42,413	27,193
C-89-14	29 76	61,000	52,130
C-89-15	35 37	64,900	54,630

FLIGHT	PAYLOAD	W_G (LBS)	W_P (LBS)
C-89-16	35	62,028	52,758
C-89-17	39	30,000	
C-89-18	40	29,500	
C-89-19	40	29,500	
C-89-20	40	29,500	
C-89-21	40	29,500	
C-89-22	40	29,500	
C-89-23	41	22,500	
C-89-24	41	22,500	
C-89-25	41	22,500	
C-89-26E	58	62,777	51,807
C-89-27	63	20,000	
C-89-28	63	20,000	
C-89-29	63	20,000	
C-89-30	63	20,000	
C-89-31	63	20,000	
C-89-32	63	20,000	
C-89-33	63	20,000	
C-89-34	63	20,000	
C-89-35	70	60,412	51,722
C-89-36	71	62,432	53,017
C-89-37	71	62,432	53,017
C-89-38	72	50,685	42,415
C-89-39	73	57,151	49,181
C-89-40	74	52,847	44,877
C-89-41	77 77	14,330	2,060

FLIGHT	PAYLOAD	W_G (LBS)	W_P (LBS)
C-89-42	77 77	14,330	2,060
C-89-43	77 77	14,330	2,060
C-90-1	2 16	53,500	41,975
C-90-2	2 16	53,500	41,975
C-90-3	3 4	37,400	27,930
C-90-4	5	37,309	29,439
C-90-5	7 30	14,920	5,550
C-90-6	14	3,500	
C-90-7	14 22	62,800	51,000
C-90-8	18 51 Mars Sample Return Payload	25,500	
C-90-9	18 51 Mars Sample Return Payload	25,500	
C-90-10E	51 Tug for C-90-8	63,200	55,930
C-99-11E	51 Tug for C-90-9	63,200	55,930
C-90-12	20	3,500	
C-90-13	20	3,500	
C-90-14	21 25 75	15,700	3,930
C-90-15	29 76	61,000	52,130
C-90-16	35 37	64,900	54,630
C-90-18	40	29,500	

FLIGHT	PAYLOAD	W_G (LBS)	W_P (LBS)
C-90-19	40	29,500	
C-90-20	40	29,500	
C-90-21	40	29,500	
C-90-22	40	29,500	
C-90-23	41	22,500	
C-90-24	41	22,500	
C-90-25	41	22,500	
C-90-26	41	22,500	
C-90-27	63	20,000	
C-90-28	63	20,000	
C-90-29	63	20,000	
C-90-30	63	20,000	
C-90-31	63	20,000	
C-90-32	63	20,000	
C-90-33	63	20,000	
C-90-34	63	20,000	
C-90-35	66 Life Science Lab Retrieval 68 Comm/Nav.Lab Placement	33,000 19,000	
C-90-36	67 Earth Obs. Lab Retrieval 69 Space Mfg.Lab Placement	25,000 25,000	
C-90-37	71	62,432	53,017
C-90-38	71	62,432	53,017
C-90-39	72 72	53,300	44,030

APPENDIX F

LIST OF ABBREVIATIONS AND DEFINITIONS

APS	Auxiliary Propulsion System
AFRPL	Air Force Rocket Propulsion Laboratory
B_o	Bond Number
CER's	Cost Estimating Relationships
CIS	Chemical Interorbital Shuttle
EOS	Earth Orbital Shuttle
ESS	Expendable Second Stage
Fr	Froude Number
GH_2	Gaseous Hydrogen
GSE	Ground Support Equipment
I_{sp}	Specific Impulse
I_t	Total Impulse
KSC	Kennedy Space Center
LH_2	Liquid Hydrogen
LO_2	Liquid Oxygen
LOX	Liquid Oxygen
MLI	Multilayer Insulation
NPSP	Net Positive Suction Pressure
OPD	Orbital Propellant Depot
OPSS	Orbital Propellant Storage System
OMS	Orbital Maneuvering System
RF	Radio Frequency
RNS	Reusable Nuclear Shuttle
S-II	Saturn Second Stage
SAK	Single Alumnized Kapton

SAM	Single Aluminized Mylar
SH_2	Slush Hydrogen
SMR	Specific Mass Requirements
SS	Space Shuttle
TFU	Theoretical First Unit (Used with Costs)
tug	Space Tug
W_p	Propellant Weight
Cargo sharing	The maximum utilization of a vehicle's payload volume or weight capability by carrying both propellant and dry payload
Cost effectiveness	A measure of the dollar cost and a system or program related to some measure of effectiveness, e.g. $ per lb. of propellant delivered to orbit. Cost effectiveness studies are conducted to compare the relative costs of alternate system programs or approaches in relation to measure of effectiveness
Hydrogen slush (slush hydrogen)	A mixture of small, solid hydrogen particles suspended in liquid hydrogen at the triple point
Linear Propellant Transfer	Acceleration of source tank and receiver tank in X axis direction to settle propellants and permit fluid pumping
Liquid/Vapor Interface Control	Management of the position in the tanks of the liquid to vapor boundaries
Mass Fraction	The ratio of usable full thrust propellant to gross weight for a space vehicle
Modular transfer	The package exchange of cargo (fluids); i.e., the replacement of an empty tank by a like tank that is full
Operational effectiveness	Any measure of how well the operation carries out its objective used for comparative purposes. It is synonymous with "effectiveness" as used in the term cost of effectiveness

Orbital storage	Sometimes referred to as storage. The accumulation and maintenance (saving) of fluid in earth orbit for subsequent transfer to a user vehicle
Program elements	Those propulsive vehicles and orbital stations which are the major hardware components of the space program
Propellant Logistics Module	Propellant tank and associated hardware fitting the shuttle orbiter cargo bay and employed for transporting propellant to the user vehicles
Propellant logistics system	That system which incorporates the transport from ground to space, transfer, and orbital storage (if required) for the purpose of propellant resupply of space-based user vehicles
Receiver tank	That tank accepting propellants in a propellant transfer operation
Rotational Propellant Transfer	Rotation of the propellant source tank and receiver tank about pitch axis to settle propellants and permit fluid pumping
Source tank	That tank supplying the propellants in a propellant transfer operation
Timelines	A sequence of activities in a mission with start and stop times (duration) of the activity defined
Traffic model	A description of the use of a particular vehicle or set of vehicles in terms of the number of trips per unit time, points of departure and destination, trip routes, and trip durations
User traffic model	Refers to the rate of flight of user vehicles
Logistic traffic model	Refers to the rate of flight of the propellant transport, transfer and storage vehicles defined in a propellant logistic system.

Traffic rate	The aspect of a traffic model description specifying the number of trips per unit time.
Transport system	System for delivering propellants from earth-to-earth orbit. The tug is not considered part of the transport system for the purpose of this definition.
Transfer	The exchange of propellant or fluid from one vehicle or spacecraft to another vehicle or spacecraft.
Tug	Space-launched vehicle for use with the Space Shuttle Orbiter, i.e., transportable in shuttle bay.
User vehicle	A space-based spacecraft which requires propellant refueling or makeup of life support fluids in earth orbit.
Orbit Maintenance	Refers to propellant expended by space-based vehicles and orbital storage facilities for orbital stationkeeping.